THE

ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY
AND ASTRONOMICAL PHYSICS

VOLUME VI NOVEMBER 1897 NUMBER 4

THE IMPORTANCE OF ASTROPHYSICAL RESEARCH AND THE RELATION OF ASTROPHYSICS TO OTHER PHYSICAL SCIENCES.[1]

By JAMES E. KEELER.

THE domains of the physical sciences are not, like the political divisions represented on a map, capable of being defined by boundary lines traced with mathematical precision. They pass into one another by imperceptible gradations, the unity of nature opposing itself to rigid systems of classification. Thus there often exists between two allied sciences a broad ground, belonging to each, yet exclusively the property of neither, which may be so extensive and fertile as to justify the development of a new science for its special cultivation. And such a science not only subserves the purpose for which it was created, but it has the further special importance that, by promoting an exchange of knowledge between its previously established neighbors, by investigating the cause of disagreements between them, by comparing their methods, and possibly by detecting errors in their results, it tends to bring them into more perfect coördination.

Such is the nature of the science which Professor Langley has called the new astronomy, and which is also, and perhaps more generally, known as astrophysics. Its high development

[1] Address delivered at the dedication of the Yerkes Observatory, Oct. 21, 1897.

has in fact been so recent that its name is found in only our latest dictionaries. It is closely allied on the one hand to astronomy, of which it may properly be classed as a branch, and on the other hand to chemistry and physics ; but it assumes wide privileges, and it is ready to draw material which it can use with profit from any source, however distant. It seeks to ascertain the nature of the heavenly bodies, rather than their positions or motions in space — *what* they are, rather than *where* they are ; and for my own convenience I shall use the terms astrophysics and astronomy to denote the sciences of which these aims are respectively characteristic. Yet here again the line of demarcation cannot be sharply drawn, since the measurement of celestial motions that cannot be dealt with by the methods of the older astronomy is one of the most important tasks of the astrophysicist. That which is perhaps most characteristic of astrophysics is the special prominence which it gives to the study of radiation. The complex nature of white light, in particular, is never lost sight of, and its consequences are thoroughly exploited.

That the older astronomers made no efforts systematically to study the nature of the heavenly bodies, is to be ascribed to the seeming hopelessness of such an attempt in their day, rather than to a lack of interest in the subject, or a slight appreciation of its importance on their part. They did in fact seek explanations of such phenomena as they could observe, and the beginnings of astrophysics are to be found far back in the past. But the curious speculations of Sir John Herschel on the structure of the Sun's photosphere show how inadequate was the supply of facts to serve as a basis for a science of solar physics in Herschel's time. The conception of living organisms a thousand miles long, floating about on the Sun's surface, and shining with the intense brilliancy of the photosphere, seems to us extraordinary, and even grotesque. To lose its strangeness it has to be considered with reference to the contemporary state of knowledge. But the fact that only fifty years ago it was regarded as an admissible supposition by one of the most eminent of astronomers helps us to realize how rapid has been the advance of

astrophysical science. It was only after the discovery was made, that the light which reveals to us the existence of the heavenly bodies also bears the secret of their constitution and physical condition, that the basis for a real science was obtained. The spectroscope placed new and hitherto undreamed of powers in the hands of men. It is to the astrophysicist what the graduated circle and the telescope are to the astronomer.

The study of astrophysics does not at present seem to have a very direct bearing on the practical affairs of everyday life. If to this statement the objection should be raised that the study of solar radiation is likely to lead to a practical method of utilizing the Sun's heat as a source of mechanical power, I should say that such a discovery (if it is ever made), is much more likely to be the result of an ingenious application of principles already known. What the future may have in store we cannot tell, but at present the statement I have made holds good. With respect to practical usefulness, therefore, astrophysics does not possess the same claims to consideration as astronomy, which has obviously important applications in furnishing standards of time, and in surveying, geodesy and navigation, and in addition to these, an immense indirect influence on thousands of ordinary affairs. Yet on such grounds it is not probable that any astronomer would care to base a claim for his science. Astronomy long ago reached that state of perfection which suffices for the practical ends I have mentioned, and is still pursued with undiminished vigor. Both astronomy and astrophysics take their stand on a higher plane, where it is a sufficient justification for their existence that they enable us better to understand the universe of which we form a part, and that they elevate the thoughts and ennoble the minds of men.

In considering the importance of astrophysical research I have, therefore, regarded the question from a purely scientific standpoint. Even with this restriction there is room for a considerable diversity of opinion, since the elimination of the human element from the question is impossible. Scientists are men. Every man is naturally inclined to attach special importance to

that in which he is himself specially interested. Personal preferences, or even prejudices, may enter into the estimation in which a branch of learning is held. But setting these aside, there are grounds for differences of opinion which are entitled to respect. What importance is to be attached, for example, to the proof, now brought almost within our grasp by the improvement of spectroscopic instruments and methods, that the law of gravity is operative within the stellar systems, as well as in the system of our own Sun? Doubtless there are some who are satisfied with the moral certainty that we already possess, and to whom the proof just mentioned would merely afford the satisfaction of inking in, on a printed form, the penciled words which had already been written in its blanks; while there are others who would regard the formal proof alone as entitled to consideration. I have even heard widely different opinions expressed by eminent astronomers as to the scientific importance of a problem so fundamental as the exact determination of the distance of the Sun.

The degree of importance which we attach to a newly discovered fact or principle is influenced by many circumstances, among which we cannot fail to recognize some of the failings of human nature. When progress is rapid, individual achievements lose their prominence, like mountain peaks rising from a high plateau. The discovery of an asteroid was once a notable event. Now it attracts little attention, outside of a small circle of observers, and it is probable that few of us could say just how many of these little bodies have been brought to light during the past year. In astrophysics discoveries of the highest significance have succeeded one another so rapidly that they are now taken as a matter of course.

The bearings of a discovery on existing knowledge are sometimes not immediately perceived, and its true scientific importance is not appreciated until these are revealed in the fullness of time. Other circumstances might be mentioned, but these are sufficient for my purpose — which is to show that there is no cause for surprise if opinions differ as to the exact value of

astrophysical research. It is because the science of astrophysics is so young—so distinctly in the formative stage—that I have ventured to discuss a question which, in due time, will settle itself.

A feature of astrophysical research which I do not wish to leave unmentioned is the interest which is felt in it by the public. Those who are interested in the results of science, but who care little for methods, and know nothing of elegant forms of analysis, are naturally more attracted by the view of the heavenly bodies which astrophysics presents, than by the view which is obtained from the standpoint of the older astronomy. Astrophysics paints its picture in the brighter colors. A star, regarded as a center of attraction, or as reference point from which to measure celestial motions, awakens little enthusiasm in the popular mind; but a star regarded as a sun, pouring out floods of light and heat as a consequence of its own contraction, torn by conflicting currents and fiery eruptions, shrouded in absorbing vapors or perhaps in vast masses of flame, appeals at once to the popular imagination. Both branches of astronomy share in the advantages which follow this awakening of popular interest; for that popular interest in any science is to be deprecated is, to my mind, utterly inadmissible. The cultivation of a pure science is possible only in those communities where such an intelligent interest exists. Without it we should not be here today. It is splendidly manifest around us. The only possible danger to be feared is, that interest in results whose significance is readily understood may lead to an undervaluation by the public of results which are of the highest importance, but which only the trained specialist can fully comprehend; and this danger will be avoided if scientific men publicly express their own appreciation of results which belong to the latter class.

Popular interest which is not of this character, but which has no purpose other than amusement, is less desirable. "It is the universal law," says Macaulay, "that whatever pursuit, whatever doctrine becomes fashionable, shall lose a portion of that dignity which it had possessed while it was confined to a small but earn-

est minority, and was loved for its own sake alone." Macaulay is here referring to a temporary interest in scientific matters which prevailed among fashionable circles in the reign of Charles the Second—to what would now be called a "fad." In our own time science occasionally suffers in much the same way. It is to be regretted that the habitability of the planets, a subject of which astronomers profess to know little, has been chosen as a theme for exploitation by the romancer, to whom the step from habitability to inhabitants is a very short one. The result of his ingenuity is that fact and fancy become inextricably tangled in the mind of the layman, who learns to regard communication with the inhabitants of Mars as a project deserving serious consideration (for which he may even wish to give money to scientific societies), and who does not know that it is condemned as a vagary by the very men whose labors have excited the imagination of the novelist. When he is made to understand the true state of our knowledge of these subjects he is much disappointed, and feels a certain resentment toward science, as if it had imposed upon him.

Science is not responsible for these erroneous ideas, which, having no solid basis, gradually die out and are forgotten. Thus it cannot long suffer from outside misapprehension, while the sustained effort necessary to real progress is, in the end, a sufficient safeguard against the intrusion of triflers into its workshops.

In astrophysics sustained effort is as necessary as it is in other branches of science. There is an impression in some quarters that the results of astrophysical investigation are easily obtained. That this is in some cases true may readily be admitted. I cannot regard it as a reproach. It is one of the advantages, to which I have referred, of bringing new methods to bear on old problems. What an effort to grasp something tangible we observe in the earlier writing on Fermat's principle! What a groping in the dark after a principle felt rather than seen! And how obvious the same principle is from the standpoint of the wave theory! In a field so wide and so little explored as astrophysics, there must be novelties which can be gathered

with comparatively little effort, and which may nevertheless be of no small importance. But there are also problems whose solution calls for the exercise of the highest intellectual faculties, and for the most strenuous exertion.

In astrophysics difficulties are met with quite different from those of physical astronomy. There a vast variety of highly complex phenomena are to be referred to the operation of a well-known and extremely simple law. The mental discipline there obtained is of the highest order, and it is hardly necessary to say that a training in the methods of the older astronomy should be regarded as an indispensable preparation for astrophysical work. But in astrophysics, as in the sciences of chemistry and biology, there are difficulties which arise from an imperfect knowledge of the laws governing the phenomena observed. The discovery of unknown laws and principles, as well as the explanation of phenomena by laws already known, is one of its most important objects.

I have referred to the differences of opinion which usually exist, with reference to the value of a new science. There may be some who view with disfavor the array of chemical, physical, and electrical appliances crowded around the modern telescope, and who look back to the observatory of the past as to a classic temple whose severe beauty had not yet been marred by modern trappings. So mankind, dissatisfied with present social conditions, looks back with tender regret to the good old times of earlier generations, yet rushes forward with the utmost speed. May we regard the eagerness of pursuit as a measure of the value of its object? That the importance of astrophysical research, considered with respect both to its own ends and to its bearing on the advance of knowledge in other fields, is already great, and that it will grow steadily from year to year, is naturally my own belief. In a general way I have considered some of the reasons on which it is founded, and I now wish to call your attention to a few specific cases, which illustrate my general remarks, and in which I think the importance of astrophysical science is manifest.

Some of the most noteworthy advances in astronomy and in astrophysics have been made possible by the introduction of photography. The photographic plate not only gives a permanent record of what the eye can see, but, by its integrating power continued through long exposures, it builds up a picture from light impulses too feeble to affect the sense of vision. Thus it has been discovered that vast regions in the sky are filled with diffuse nebulæ, which (since the apparent brightness of a surface cannot be increased by any optical device) must ever remain unseen. This information, which the photographic plate alone could furnish, is itself most wonderful and suggestive. It is however but a part of what the same plate may yield. Whoever has studied Professor Barnard's admirable pictures of the Milky Way in Scorpio must have observed how accurately the distribution of the smallest stars corresponds to that of the extended nebulosity which fills this part of the sky, and at the same time how strikingly the nebulous matter is concentrated around the brightest stars in the constellation. Bright stars, faint stars, and nebulosity are unmistakably physically related, and hence at the same order of distance from the Earth; and from this it follows that the real sizes of the stars are of entirely different orders. Here is a fact having a most important bearing on the question of stellar distribution, brought out by the simplest possible means. It is perhaps beyond the reach of more elaborate methods. And in this case it is to be observed that the evidence would not be made clearer by any further treatment of the material. The positions of the stars and the density of the nebulosity might be measured, and the results might be tabulated, but all to no purpose; for, if the data yielded by observation were in the form of measurements, the first step toward their interpretation would be the construction of just such a chart as the photograph places ready in our hands.

Of very great importance to the new astronomy has been the investigation of the conditions of maximum efficiency of its chief instrument, the spectroscope, by the methods of physical

optics. The theory of resolving power, introduced by Lord Rayleigh, and quite recently elaborated by Professor Wadsworth, has been especially fruitful. It has done away with the old idea that the efficiency of a spectroscope is measured by its dispersion, and may be trusted to destroy in time some musty traditions concerning the magnifying power and definition of astronomical telescopes. The theory has also been extended so as to include the spectrograph, in which the photographic plate takes the place of the eye at the observing telescope of the spectroscope. The designing of spectroscopes has thus been placed on a thoroughly scientific basis. At the same time the demands for accuracy in the practical construction of the instrument have been greatly raised. The objectives, the prisms, the fitting of the mechanical parts must be the best possible. Hence the spectroscope has become an instrument of precision, worthy of a place among the most refined instruments of practical astronomy, and fitted for the class of work now most needed in astrophysical research.

A familiar example of the mutual obligations of allied sciences is found in the first measurements of the velocity of light. Perhaps a somewhat parallel case may have to be recorded by the future historian of science. Spectroscopists have tested the validity of what is known as Doppler's principle, by which the motion of a body in the line of sight is determined from the observed displacement of its spectral lines, and have at the same time proved the capabilities of their instruments, by means of the velocities of the Earth and heavenly bodies furnished to them by astronomy. It is not impossible that this also is a reversible process, and that measurements of the velocities of bodies in the solar system may give one of the best methods of determining the dimensions of their orbits.

Numerous cases could be mentioned in which astrophysical investigations have contributed to our knowledge of the chemical elements. Of these the first which naturally presents itself is one of the most recent. The element helium was discovered first in the Sun (as its name implies), then in the stars, then in

the nebulæ, and at last, by Professor Ramsay, it was "run to earth." It had an important place in celestial chemistry long before it was known to terrestrial science; and, on account of its rare occurrence and seeming inertness, it is quite possible that but for the spectroscope of the astrophysicist we should have remained forever ignorant of its existence. To the astrophysicist, however, it was known only by the occurrence in its spectrum of one bright line. Laboratory investigations soon revealed its complete spectrum, and then the astrophysicists were able to recognize, as belonging to helium, a large number of lines whose origin in the heavenly bodies they had been unable to discover. Our knowledge of the heavenly bodies may be greatly advanced when the properties of this remarkable element shall have been more thoroughly studied.

It is not necessary, however, to seek illustrations in new elements. The complete series of hydrogen lines, to which belong the few lines that are ordinarily seen in the laboratory spectroscope, was discovered by Huggins in the spectra of the white stars, and a new series, which had previously been seen by the eye of theory only, and which, so far as I know, has not yet been produced artificially, has recently been found by Pickering in the spectrum of the star Zeta Puppis.

Another familiar element is calcium. Its ordinary properties are well understood. But under the conditions met with in the Sun and stars it behaves in a mysterious manner. Notwithstanding its considerable atomic weight, it floats quietly high above the surface of the Sun, where other heavy metals are only occasionally present in consequence of violent eruptions. It is true that the apparently abnormal spectrum of calcium under these conditions has been shown by Sir William and Lady Huggins to be merely the result of extreme tenuity of the luminous vapor; but the existence of calcium at such great heights, under any conditions whatsoever, seems to point to some remarkable property of the element which is unrecognizable by the methods of ordinary chemistry.

The spectrum of a substance is not the same under all cir-

cumstances. In some cases a change occurs suddenly when certain critical conditions are reached; in others the change is gradual and progressive. By studying these changes in laboratory experiments, and comparing them with what we see in the observatory, we are able to arrive at some definite conclusions respecting the conditions which prevail in the stars, while the same comparison often throws light on the phenomena observed in the laboratory. It has been shown, for instance, that the spectrum of magnesium gives a means of estimating the temperatures of the stars; and the same criterion enables us to recognize in the stars temperatures vastly exceeding the highest that have been produced on the Earth. Thus the science of astrophysics allows us to extend our investigations to temperatures which the resources of the laboratory cannot furnish.

It may be well to mention an example of the difficulties, to which I have referred, arising from our imperfect knowledge of the laws which underlie phenomena constantly observed: Recent comparisons of the spectra of the Sun and metals, made at the Johns Hopkins University with the concave grating spectroscope of Professor Rowland, have proved that spectral lines may not merely be widened by increased pressure of the radiating vapor, but that they may be shifted bodily; while the still more recent investigations of Zeeman show that a line may be widened (and at the same time doubled) under the influence of a strong magnetic field. It is true that in both cases the effect produced is very small. It could not lead to mistakes in identifying stellar lines, or to appreciable errors in measuring celestial motions. But the fact that the spectrum of a substance varies according to circumstances which are as yet only imperfectly understood, shows us the necessity of exercising caution in interpreting the spectral phenomena presented to us by the heavenly bodies. At present these spectral variations increase the difficulties that the astrophysicist has to contend with. Eventually they will become additional and most valuable sources of information.

The discovery by Kayser and Runge of line series in the spectra of the common elements has a most important bearing

on the work of the astrophysicist. It provides him with the means, long greatly needed, of deciding with certainty whether or not lines in celestial spectra are identical with lines in the spectra of terrestrial substances. On the other hand, as we have already seen, he is sometimes able to supply the physicist with missing data.

From the standpoint of the older astronomy, the most important result of the introduction of new methods has been the determination of motions in the line of sight by means of the spectroscope. The method has been tested so often, and with such uniform success, that there is no longer any doubt as to the correctness of the principle on which it is based, or to the accuracy of the results which it is capable of yielding in competent hands. It is directly applicable to one of the great problems of astronomy—the determination of the direction and rate of the Sun's drift through space. From the proper motions of the stars, furnished by the methods of the older astronomy, the direction of the Sun's motion can be deduced, and, under certain assumptions as to the stars' distances, the rate of motion; but it is evident that the latter element of the problem must be subject to very considerable uncertainty. With the spectroscope velocities are directly measured, in miles per second. The two methods may be combined. It is probable that the most accurate determination of the *direction* of the Sun's drift can be obtained by comparing proper motions, while the most accurate value of the *velocity* is that given by the spectroscope. Thus, by the coöperation of the two branches of astronomy, there is measured in space a base line of constantly increasing length, for a great sidereal triangulation. At present the material afforded by spectroscopic observation is not sufficient for this great work. The observations must be treated statistically, and statistical methods can be applied successfully to only a large mass of data. What is now needed, therefore, is observations of more stars—*i. e.*, fainter stars; and the German government is building a large telescope for the Observatory at Potsdam, where photography was first applied to this class of

observations, in order that the work may be continued. There is room, however, for the employment of other large telescopes in the same field. The multiplication of observations for this purpose is no more to be deprecated than the multiplication of observations for the exact determination of star places.

Solar physics, from which the wider science of astrophysics has been evolved, offers problems so numerous and so complicated that I cannot even mention them, still less enter into a discussion of their bearing on other branches of knowledge. And what can I possibly say of their importance? The Sun is to us the grandest of material objects. It is the source of practically all our light and heat; of practically all our mechanical power; absolutely the support of all our lives. What wonder that we seek for knowledge of its nature by all the ways that we can find! These ways are opened through astrophysical research. In few of the inquiries that I have referred to can the method of light analysis be dispensed with. In most of them it offers the only chance of success.

I have time to mention only one new method of solar research. The most notable contribution to solar physics within the last few years has been the invention of the spectroheliograph by Hale and Deslandres. With this instrument photographs of the Sun are taken by strictly monochromatic light, which may be chosen from any part of the spectrum. If the part selected is the middle of the K line, the picture essentially represents the distribution of calcium vapor on the disk of the Sun, and the presence of other elements is ignored. This is, in fact, the line usually chosen, partly on account of the conspicuous rôle played by calcium in solar phenomena, and partly for other reasons which it is not necessary to state. The possibilities of the method are obvious. By an ingenious modification of his instrument, Hale now photographs on a single plate the Sun covered with all its spots and faculæ, and surrounded by all its prominences; and all this is done in a few minutes, in daylight! Could the corona be added, the triumph would be complete;

but the corona yet remains unconquered in its stronghold, though the attack is being vigorously pushed.

No branch of observational astronomy seems to be in so backward a state as the representation of the surface features of the planets. Although the Moon has been photographed with splendid success, and the planets with results that are encouraging and suggestive, we still rely (in the case of the planets) on the old method of hand-drawing used by Galileo. The fallibility of the draftsman is well known. It has been illustrated again and again. Yet there seems to be a curious habit among some observers of regarding a drawing, when once made, as invested with high authority—as that of a standard established by legislative act. A photograph, if it could be made, would be free from the errors of the draftsman, and from a personality which is recognizable in all hand-drawings, and which, though it is scarcely to be classed as an error, it would be desirable to avoid. Here, then, is another opportunity for the new methods. There is no reason to suppose that it is impossible to obtain photographs of the planets which will show all that the eye can see, although there are many reasons to know that it will be very difficult to do so. The instruments for this purpose would have to be quite different from those in general use, and there would be few occasions, in even the most favored regions of the Earth, when they could be employed. Difficulties would also arise from the rapid rotation of some of the planets. But this is not the place to discuss the necessary conditions. It is only fair to say that Professor Schaeberle, of the Lick Observatory, has already been experimenting in this direction—with what success is not yet generally known.

Passing to stellar spectroscopy, a field broader even than that of solar physics is opened before us, for the Sun, although paramount in his own system, is only one of the stars. In a general way, the spectra of the stars have been observed and classified according to their character, and objects of unusual interest have been noted for future investigation; many a rare specimen has been meshed in Harvard's widely extended net; but the detailed

study of individual spectra has just begun. For this purpose large telescopes are desirable, if not absolutely necessary. Many observations of precision required in the older astronomy are best made with small telescopes. But in stellar spectroscopy light is all-important, and while much can doubtless be accomplished with small telescopes, there is probably nothing that cannot be done better with large ones. Even in solar spectroscopy, where the supply of light is abundant, a large image is required for the study of individual parts of the Sun's surface.

No department of astrophysics has profited more by the introduction of photographic processes than stellar spectroscopy. To the advantages of photography already mentioned there is here to be added another not less important. Owing to atmospheric disturbances the image of a star dances about on the slit-plate of a spectroscope placed in the focus of a telescope. The spectrum is not only faint, but tremulous, and to measure the lines in it by visual observation is like trying to read a printed page irregularly illuminated by flashes of light. These irregularities do not appear on the photograph. They disappear in the process of integration. Negatives obtained with the spectrograph can be directly measured under a microscope, or enlargements can be made from them in the usual manner. In this way photographs of star spectra are now made which are comparable, with respect to accuracy and wealth of detail, to Kirchhoff's famous map of the solar spectrum. "It is simply amazing," says Professor Young, with reference to the Draper Memorial photographs, "that the feeble, twinkling light of a star can be made to produce such an autographic record of the substance and condition of the inconceivably distant luminary."

Let us consider for a moment some of the questions in this field that are open for investigation. The motions in the line of sight of all stars within reach of the largest telescopes have to be measured. This important line of research has already been referred to. The relation has to be ascertained between the various classes of star spectra and the probable order of stellar evolution. It now appears practically certain that all the stars

are not made according to a single pattern, and that they cannot be fitted into a single scheme of development. The Wolf-Rayet stars, the stars with banded spectra, the stars with bright-line spectra, the planetary nebulæ, the spectroscopic binaries, and the variable stars require the most careful attention. Variables of the Mira class should be followed with the spectroscope as far as possible from their maximum, and the spectral changes which accompany the light variation of other stars, whether due to phenomena of emission and absorption, or to relative motion of bodies in a revolving system, should be studied with the most powerful instruments.

The discovery by means of the spectroscope of binary stars which are far too close for resolution with our most powerful telescopes, and which are recognized in their true character by a periodic doubling of their spectral lines, has brought to our knowledge strange and wonderful conditions of orbital motion. Such a system as that of Spica, where two bodies like our Sun revolve around each other like the balls of a gigantic pendulum, in a period of only four days, at a distance no greater than that which separates the sixth satellite of Saturn from its primary, must have remained forever unknown to the older astronomy. Between these spectroscopic binaries and the most rapidly revolving doubles visible in the telescope there is a wide gap, the cause of which is obvious. The conditions favorable to discovery in the two cases are directly opposed, and doubtless a large class of stars lies at present just beyond the reach of either method.

But this gap may be bridged over by means of such a great telescope as we see before us today, while the work necessary to accomplish this end will open up still another field for research. It has long been recognized that the position micrometer and the spectroscope, taken together, are theoretically competent to determine the real orbits in space of the components of a double star; hence, also, the masses of the components, and their distance from the earth. Until recently the question had only a mathematical interest. But the small veloci-

ties to be expected in the case of any double star whose components can be separately distinguished with the telescope are now almost, if not quite, within reach of the spectroscope, and the investigation of such doubles has acquired a physical interest.

Here I must close my review of the important questions before the astrophysicist, with the consciousness that it is most remarkable for what it leaves unnoticed. I have said nothing of questions relating to the photography of comets and their spectra, the rotation of the planets or the absorption spectra of their atmospheres, the colors of double stars, the spectra of temporary stars, the measurement of obscure wave-lengths; nothing about stellar photometry, the application of interference methods to spectroscopic research, the exploration of the infra-red spectrum. But I will not trespass further on your patience. In all the fields that I have mentioned there are noble problems, worthy of the best efforts that can be given to their solution. To realize their importance think how ill we could spare what we have already won. What a blank would be left in our knowledge of the heavens if the results of astrophysical research in our own generation were stricken out!

The future should look bright indeed, as we view it today. Munificence and skill have provided this splendid Observatory with means for promoting knowledge in both the older and the newer branches of the sublime science to which it is dedicated. Its magnificent equipment will be used by men who have won merited distinction in both the older and the newer methods of research. It has the coöperation and support of a great institution of learning. From this happy union of ability and opportunity we have reason to expect results of the highest import to the new astronomy, and to its allied branches of physical science.

But, lest any words of mine should give rise to expectations that may not be fulfilled, I wish to say once more that important results are not necessarily of a striking or surprising character. We can hardly assume that every increase in telescopic power

will be followed by the discovery of new planets or satellites. Such discoveries, if they come, will be welcome; but they should not be expected. There may be no planets or satellites, yet undiscovered, in the solar system. But we may confidently expect from the work of this Observatory those results which throw light on the dark places in nature, and which, therefore, though they may not stimulate the popular imagination, are of the very highest importance, for they are indispensable to true scientific progress.

ASPECTS OF AMERICAN ASTRONOMY.[1]

By Simon Newcomb.

The University of Chicago yesterday accepted one of the most munificent gifts ever made for the promotion of any single science and with appropriate ceremonies dedicated it to the increase of our knowledge of the heavenly bodies.

The president of your university has done me the honor of inviting me to supplement what was said on that occasion by some remarks of a more general nature suggested by the celebration. One is naturally disposed to say first what is uppermost in his mind. At the present moment this will naturally be the general impression made by what has been seen and heard. The ceremonies were attended, not only by a remarkable delegation of citizens, but by a number of visiting astronomers, which seems large when we consider that the profession itself is not at all numerous in any country. As one of these, your guests, I am sure that I give expression only to their unanimous sentiment in saying that we have been extremely gratified in many ways by all that we have seen and heard. The mere fact of so munificent a gift to science cannot but excite universal admiration. We knew well enough that it was nothing more than might have been expected from the public spirit of this great West; but the first view of a towering snow peak is none the less impressive because you have learned in your geography how many feet high it is, and great acts are none the less admirable because they correspond to what you have heard and read, and might therefore be led to expect.

The next gratifying feature is the great public interest excited by the occasion. That the opening of a purely scientific institution should have led so large an assemblage of citizens to devote an entire day, including a long journey by rail,

[1] Address delivered at the University of Chicago, Oct. 22, 1897, in connection with the dedication of the Yerkes Observatory.

to the celebration of yesterday is something most suggestive from its unfamiliarity. A great many scientific establishments have been inaugurated during the last half century, but if on any such occasion so large a body of citizens has gone so great a distance to take part in the inauguration the fact has at the moment escaped from my mind.

That the interest thus shown is not confined to the hundreds of attendants, but must be shared by your great public, is shown by the unfailing barometer of journalism. Here we have a field in which the nonsurvival of the unfit is the rule in its most ruthless form; the journals that we see and read are merely the fortunate few of a countless number, dead and forgotten, that did not know what the public wanted to read about. The eagerness shown by the representatives of your press in recording everthing your guests would say was accomplished by an enterprise in making known everything that occurred and, in case of an emergency requiring a heroic measure, what did not occur, showing that smart journalists of the East must have learned their trade, or at least breathed their inspiration in these regions. I think it was some twenty years since I told a European friend that the eighth wonder of the world was a Chicago daily newspaper. Since that time the course of journalistic enterprise has been in the reverse direction, to that of the course of empire eastward, instead of westward.

It has been sometimes said — wrongfully I think — that scientific men form a mutual admiration society. One feature of the occasion made me feel that we, your guests, ought then and there to have organized such a society, and forthwith proceeded to business — this feature consisted in the conferences on almost every branch of astronomy by which the celebration of yesterday was preceded. The fact that beyond the acceptance of a graceful compliment I contributed nothing to these conferences relieves me from the charge of bias or self-assertion in saying that they gave me a new and most inspiring view of the energy now being expended in research by the younger generation of astronomers. All the experience of the past leads us to believe

that this energy will reap the reward which nature always bestows upon those who seek her acquaintance from unselfish motives. In one way it might appear that little was to be learned from a meeting like that of the present week—each astronomer may know by publications pertaining to the science what all the others are doing. But knowledge, obtained in this way, has a sort of abstractness about it a little like our knowledge of the progress of civilization in Japan, or of the great extent of the Australian continent. It was, therefore, a most happy thought on the part of your authorities to bring together the largest possible number of visiting astronomers from Europe as well as America, in order that each might see, through the attrition of personal contact, what progress the others were making in their researches. To the visitors at least I am sure that the result of this meeting has been extremely gratifying. They earnestly hope, one and all, that the callers of the conference will not themselves be more disappointed in its results; that however little they may have actually to learn of methods and results, they will feel stimulated to well directed efforts and find themselves inspired by thoughts which, however familiar, will now be more easily worked out.

We may pass from the aspects of the case as seen by the strictly professional class to those general aspects fitted to excite the attention of the great public. From the point of view of the latter it may well appear that the most striking feature of the celebration is the great amount of effort which it shows to be devoted to the cultivation of a field quite outside the ordinary range of human interests.

A little more than two centuries ago Huyghens prefaced an account of his discoveries on the planet Saturn with the remark that many, even among the learned, might think he had been devoting to things too distant to interest mankind an amount of study which would better have been devoted to subjects of more immediate concern. It must be admitted that this fear has not deterred succeeding astronomers from pursuing their studies. The enthusiastic students whom we see around

us are only a detachment from an army of investigators who, in many parts of the world, are seeking to explore the mysteries of creation. Why so great an expenditure of energy? Certainly not to gain wealth, for astronomy is perhaps the one field of scientific work which, in our expressive modern phrase, "has no money in it." It is true that the great practical use of astronomical science to the country and the world in affording us the means of determining positions on land and at sea is frequently pointed out. It is said that an Astronomer Royal of England once calculated that every meridian observation of the Moon made at Greenwich was worth a pound sterling, on account of the help it would afford to the navigation of the ocean. An accurate map of the United States cannot be constructed without astronomical observations at numerous points scattered over the whole country, aided by data which great observatories have been accumulating for more than a century, and must continue to accumulate in the future.

But neither the measurement of the Earth, the making of maps, nor the aid of the navigator is the main object which the astronomers of today have in view. If they do not quite share the sentiment of that eminent mathematician, who is said to have thanked God that his science was one which could not be prostituted to any useful purpose, they still know well that to keep utilitarian objects in view would only prove a handicap on their efforts. Consequently, they never ask in what way their science is going to benefit mankind.

As the great captain of industry is moved by the love of wealth, and the politician by the love of power, so the astronomer is moved by the love of knowledge for its own sake, and not for the sake of its application. Yet he is proud to know that his science has been worth more to mankind than it has cost. He does not value its results merely as a means of crossing the ocean or mapping the country, for he feels that man does not live by bread alone. If it is not more than bread to know the place we occupy in the universe, it is certainly something which we should place not far behind the means of subsistence. That we now

look upon a comet as something very interesting, of which the sight affords us a pleasure unmixed with fear of war, pestilence, or other calamity, and of which we therefore wish the return, is a gain we cannot measure by money. In all ages astronomy has been an index to the civilization of the people who cultivated it. It has been crude or exact, enlightened or mingled with superstition, according to the current mode of thought. When once men understand the relation of the planet on which they dwell to the universe at large, superstition is doomed to speedy extinction. This alone is an object worth more than money.

Astronomy may fairly claim to be that science which transcends all others in its demands upon the practical application of our reasoning powers. Look at the stars that stud the heavens on a clear evening. What more hopeless problem to one confined to earth than that of determining their varying distances, their motions, and their physical constitution? Everything on earth we can handle and investigate. But how investigate that which is ever beyond our reach, on which we can never make an experiment? On certain occasions we see the Moon pass in front of the Sun and hide it from our eyes. To an observer a few miles away the Sun was not entirely hidden, for the shadow of the Moon in a total eclipse is rarely one hundred miles wide. On another continent no eclipse at all may have been visible. Who shall take a map of the world and mark upon it the line on which the Moon's shadow will travel during some eclipse a hundred years hence? Who shall map out the orbits of the heavenly bodies as they are going to appear in a hundred thousand years? How shall we ever know of what chemical elements the Sun and the stars are made? All this has been done, but not by the intellect of any one man. The road to the stars has been opened only by the efforts of many generations of mathematicians and observers, each of whom began where his predecessor had left off. We have reached a certain stage where we know much about the heavenly bodies.

We have mapped out our solar system with great precision. But how with that great universe of millions of stars in which

our solar system is only a speck of star dust, a speck which a traveler through the wilds of space might pass a hundred times without notice? We have learned much about this universe, though our knowledge of it is still dim. We see it as a traveler on a mountain top sees a distant city in a cloud of mist, by a few specks of glimmering light from steeples or roofs. We want to know more about it, its origin and its destiny; its limits in time and space, if it has any; what function it serves in the universal economy. The journey is long, yet we want, in knowledge at least, to reach the stars. Hence we build observatories and train observers and investigators. Slow indeed is progress in the solution of the greatest of problems, when measured by what we want to know. Some questions may require centuries, others thousands of years for their answer. And yet never was progress more rapid than during our time. In some directions our astronomers of today are out of sight of those of fifty years ago; we are even gaining heights which, twenty years ago, looked hopeless. Never before had the astronomer so much work, good, hard, yet hopeful work before him as today. He who is leaving the stage feels that he has only begun, and must leave his successors with more to do than his predecessors left him.

To us an interesting feature of this progress is the part taken in it by our own country. The science of our day, it is true, is of no country. Yet we very appropriately speak of American science from the fact that our traditional reputation has not been that of a people deeply interested in the higher branches of intellectual work. Men yet living can remember when in the eyes of the universal church of learning all cisatlantic countries, our own included, were *partes infidelium*.

Yet American astronomy is not entirely of our generation. In the middle of the last century Professor Winthrop, of Harvard, was an industrious observer of eclipses and kindred phenomena, whose work was recorded in the transactions of learned societies. But the greatest astronomical activity during our colonial period was that called out by the transit of Venus in 1769, which was visible in this country. A committee of the

American Philosophical Society, at Philadelphia, organized an excellent system of observations, which we now know to have been fully as successful, perhaps more so, than the majority of those made on other continents, owing mainly to the advantages of air and climate. Among the observers was the celebrated Rittenhouse, to whom is due the distinction of having been the first American astronomer whose work has an important place in the history of the science. In addition to the observations which he has left us, he was the first inventor or proposer of the collimating telescope, an instrument which has become almost a necessity wherever accurate observations are made. The fact that the subsequent invention by Bessel was quite independent, does not detract from the merits of either.

Shortly after the transit of Venus, which I have mentioned, the War of the Revolution commenced. The generation which carried on that war, and the following one which formed our constitution and laid the bases of our political institutions, were naturally too much occupied with these great problems to pay much attention to pure science. While the great mathematical astronomers of Europe were laying the foundation of celestial mechanics their meetings were a sealed book to everyone on this side of the Atlantic, and so remained until Bowditch appeared, early in the present century. His translation of the *Mécanique Céleste* made an epoch in American science by bringing the great work of Laplace down to the reach of the best American students of his time.

American astronomers must always honor the names of Rittenhouse and Bowditch. And yet, in one respect, their work was disappointing of results. Neither of them was the founder of a school. Rittenhouse left no successor to carry on his work. The help which Bowditch afforded his generation was invaluable to isolated students who, here and there, dived alone and unaided into the mysteries of the celestial motions. His work was not mainly in the field of observational astronomy, and therefore did not materially influence that branch of the science. In 1832 Professor Airy, afterward Astronomer Royal of England, made a

report to the British Association on the condition of practical astronomy in various countries. In this report he remarked that he was unable to say anything about American astronomy because, so far as he knew, no public observatory existed in the United States.

William C. Bond, afterward famous as the first director of Harvard Observatory, was at that time making observations with a small telescope, first near Boston, and afterward at Cambridge. But with so meager an outfit, his establishment could scarcely lay claim to being an astronomical observatory, and it was not surprising if Airy did not know anything of his modest efforts.

If at this time Professor Airy had extended his investigations into yet another field, with a view of determining the prospects for a great city at the site of Fort Dearborn, on the southern shore of Lake Michigan, he would have seen as little prospect of civic growth in that region as of a great development of astronomy in the United States at large. A plat of the proposed town of Chicago had been prepared two years before, when the place contained perhaps half a dozen families. In the same month in which Professor Airy made his report, August 1832, the people of that place, then numbering twenty-eight voters, decided to become incorporated, and selected five trustees to carry on their government.

In 1837 a city charter was obtained from the legislature of Illinois. The growth of this infant city, then small even for an infant, into the great commercial metropolis of the West, has been the just pride of its people and the wonder of the world. I mention it now because of a remarkable coincidence. With this civic growth has quietly gone on another, little noted by the great world, and yet in its way equally wonderful and equally gratifying to the pride of those who measure greatness by intellectual progress. If it be true that in nature nothing is great but man; in man nothing is great but mind; then may knowledge of the universe be regarded as the true measure of progress. I therefore invite attention to the fact that American

astronomy began with your city, and has slowly but surely kept pace with it until today our country stands second only to Germany in the number of researches being prosecuted, and second to none in the number of men who have gained the highest recognition by their labors.

In 1836 Professor Albert Hopkins, of Williams College, and Professor Elias Loomis, of Western Reserve College, Ohio, both commenced little observatories. Professor Loomis went to Europe for all his instruments, but Hopkins was able even then to get some of his in this country. Shortly afterward a little wooden structure was erected by Captain Gilliss on Capitol Hill at Washington, and supplied with a transit instrument for observing Moon culminations in conjunction with Captain Wilkes, who was then setting out on his exploring expedition to the southern hemisphere. The date of these observatories was practically the same as that on which a charter for the city of Chicago was obtained from the legislature. With their establishment the population of your city had increased to 703.

The next decade, 1840 to 1850, was that in which our practical astronomy seriously commenced. The little observatory of Captain Gilliss was replaced by the Naval Observatory, erected at Washington during the years 1843–4 and fitted out with what were then the most approved instruments. About the same time the appearance of the great comet of 1843 led the citizens of Boston to erect the Observatory of Harvard College. Thus it is little more than a half century since the two principal observatories in the United States were established. But we must not for a moment suppose that the mere erection of an observatory can mark an epoch in scientific history. What must have made the decade of which I speak ever memorable in American astronomy was not merely the erection of buildings, but the character of the work done by astronomers away from them as well as in them.

The Naval Observatory very soon became famous by two remarkable steps which raised our country to an important position among those applying modern science to practical uses. One

of these consisted of the researches of Sears Cook Walker on the motion of the newly discovered planet Neptune. He was the first astronomer to determine fairly good elements of the orbit of that planet, and, what is yet more remarkable, he was able to trace back the movement of the planet in the heavens for half a century, and to show that it had been observed as a fixed star by Lalande in 1795, without the observer having any suspicion of the true character of the object.

The other work to which I refer was the application to astronomy and to the determination of longitudes of the chronographic method of registering transits of stars or other phenomena requiring an exact record of the instant of their occurrence. It is to be regretted that the history of this application has not been fully written. In some points there seems to be as much obscurity as with the discovery of ether as an anæsthetic, which took place about the same time. Happily no such contest has been fought over the astronomical as over the surgical discovery—the fact being that all who were engaged in the application of the new method were more anxious to perfect it than they were to get credit for themselves. We know that Saxton of the Coast Survey, Mitchell and Locke, of Cincinnati, Bond at Cambridge, as well as Walker and other astronomers at the Naval Observatory, all worked at the apparatus, that Maury seconded their efforts with untiring zeal, that it was used to determine the longitude of Baltimore as early as 1844 by Captain Wilkes, and that it was put into practical use in recording observations at the Naval Observatory as early as 1846.

At the Cambridge Observatory the two Bonds, father and son, speedily began to show the stuff of which the astronomer is made. A well-devised system of observations was put in operation. The discovery of the dark ring of Saturn and of a new satellite to that planet gave additional fame to the establishment.

Nor was activity confined to the observational side of the science. The same decade of which I speak was marked by the beginning of Professor Pierce's mathematical work, especially

his determination of the perturbations of Uranus and Neptune. At this time commenced the work of Dr. B. A. Gould, who soon became the leading figure in American astronomy. Immediately on graduating at Harvard in 1845, he determined to devote all the energies of his life to the prosecution of his favorite science. He studied in Europe for three years, took the doctor's degree at Göttingen, came home, founded the *Astronomical Journal*, and took an active part in that branch of the work of the Coast Survey which included the determination of longitudes by astronomical methods.

An episode which may not belong to the history of astronomy must be acknowledged to have had a powerful influence in exciting public interest in that science. Professor O. M. Mitchell, the founder and first director of the Cincinnati Observatory, made the masses of our intelligent people acquainted with the leading facts of astronomy by courses of lectures which, in lucidity and eloquence, have never been excelled. The immediate object of the lectures was to raise funds for establishing his observatory and fitting it out with a fine telescope. The popular interest thus excited in the science had an important effect in leading the public to support astronomical research. If public support, based on public interest, is what has made the present fabric of American astronomy possible, then should we honor the name of a man whose enthusiasm leavened the masses of his countrymen with interest in our science.

The Civil War naturally exerted a depressing influence upon our scientific activity. The cultivator of knowledge is no less patriotic than his fellow-citizens, and vies with them in devotion to the public welfare. The active interest which such cultivators took, first in the prosecution of the war and then in the restoration of the union, naturally distracted their attention from their favorite pursuits. But no sooner was political stability reached than a wave of intellectual activity set in, which has gone on increasing up to the present time. If it be true that never before in our history has so much attention been given to education as now; that never before did so many men devote

themselves to the diffusion of knowledge, it is no less true that never was astronomical work so energetically pursued among us as now.

One deplorable result of the Civil War was that Gould's *Astronomical Journal* had to be suspended. Shortly after the restoration of peace, instead of reëstablishing the journal, its founder conceived the project of exploring the southern heavens. The northern hemisphere being the seat of civilization, that portion of the sky which could not be seen from our latitudes was comparatively neglected. What had been done in the southern hemisphere was mostly the occasional work of individuals and of one or two permanent observatories. The latter were so few in number and so meager in their outfit that a splendid field was open to the inquirer. Gould found the patron which he desired in the government of the Argentine Republic, on whose territory he erected what must rank in the future as one of the memorable astronomical establishments of the world. His work affords a most striking example of the principle that the astronomer is more important than his instruments. Not only were the means at the command of the Argentine Observatory slender in the extreme when compared with those of the favored institutions of the North, but, from the very nature of the case, the Argentine Republic could not supply trained astronomers. The difficulties thus growing out of the administration cannot be overestimated. And yet the sixteen great volumes in which the work of the institution has been published will rank in the future among the classics of astronomy.

Another wonderful focus of activity, in which one hardly knows whether he ought most to admire the exhaustless energy or the admirable ingenuity which he finds displayed, is the Harvard Observatory. Its work has been aided by gifts which have no parallel in the liberality that prompted them. Yet without energy and skill such gifts would have been useless. The activity of the establishment includes both hemispheres. Time would fail to tell how it has not only mapped out important regions of the heavens from the north to the south pole, but

analyzed the rays of light which come from hundreds of thousands of stars by recording their spectra in permanence on photographic plates.

The work of the establishment is so organized that a new star cannot appear in any part of the heavens, nor a known star undergo any noteworthy change, without immediate detection by the photographic eye of one or more little telescopes, all seeing and never sleeping policemen, that scan the heavens unceasingly while the astronomer may sleep, and report in the morning every case of irregularity in the proceedings of the heavenly bodies.

Yet another example, showing what great results may be obtained with limited means is afforded by the Lick Observatory, on Mount Hamilton, California. During the ten years of its activity its astronomers have made it known the world over by works and discoveries too varied and numerous to be even mentioned at the moment.

The astronomical work of which I have thus far spoken has been almost entirely that done at observatories. I fear that I may in this way have strengthened an erroneous impression that the seat of important astronomical work is necessarily connected with an observatory. In must be admitted that an institution which has a local habitation and a magnificent building commands public attention so strongly that valuable work done elsewhere may be overlooked. A very important part of astronomical work is done away from telescopes and meridian circles, and requires nothing but a good library for its prosecution. One who is devoted to this side of the subject may often feel that the public does not appreciate his work at its true relative value, from the very fact that he has no great buildings or fine instruments to show. I may, therefore, be allowed to claim as an important factor in the American astronomy of the last half century an institution of which few have heard and which has been overlooked because there was nothing about it to excite attention.

In 1849 the *American Nautical Almanac* office was estab-

lished by a congressional appropriation. The title of this publication is somewhat misleading in suggesting a simple enlargement of the family almanac which the sailor is to hang up in his cabin for daily use. The fact is that what started more than a century ago as a nautical almanac has since grown into an astronomical ephemeris for the publication of everything pertaining to times, seasons, eclipses and the motions of the heavenly bodies. It is the work in which astronomical observations made in all the great observatories of the world are ultimately utilized for scientific and public purposes. Each of the leading nations of western Europe issues such a publication. When the preparation and publication of the American ephemeris was decided upon the office was first established in Cambridge, the seat of Harvard University, because there could most readily be secured the technical knowledge of mathematics and theoretical astronomy necessary for the work.

A field of activity was thus opened, of which a number of able young men who have since earned distinction in various walks of life availed themselves. The head of the office, Commander Davis, adopted a policy well fitted to promote their development. He translated the classic work of Gauss, *Theoria Motus Corporum Cœlestium*, and made the office a sort of informal school, not, indeed, of the modern type, but rather more like the classic grove of Hellas, where philosophers conducted their discussions and profited by mutual attrition. When, after a few years of experience, methods were well established and a routine adopted, the office was removed to Washington, where it has since remained. The work of preparing the ephemeris has, with experience, been reduced to a matter of routine which may be continued indefinitely, with occasional changes in methods and data and improvements to meet the increasing wants of investigators.

The mere preparation of the ephemeris includes but a small part of the work of mathematical calculation and investigation required in astronomy. One of the great wants of the science today is the re-reduction of the observations made during the

first half of the present century, and even during the last half of the preceding one. The labor which could profitably be devoted to this work would be more than that required in any one astronomical observatory. It is unfortunate for this work that a great building is not required for its prosecution because its needfulness is thus very generally overlooked by that portion of the public interested in the progress of science. An organization especially devoted to it is one of the scientific needs of our time.

In such an epoch-making age as the present it is dangerous to cite any one step as making a new epoch. Yet it may be that when the historian of the future reviews the science of our day he will find the most remarkable feature of the astronomy of the last twenty years of our century to be the discovery that this steadfast Earth of which the poets have told us is not after all quite steadfast; that the north and south poles move about a very little, describing curves so complicated that they have not yet been fully marked out. The periodic variations of latitude thus brought about were first suspected about 1880, and announced with some modest assurance by Küstner, of Berlin, a few years later. The progress of the views of astronomical opinion from incredulity to confidence was extremely slow until, about 1890, Chandler, of the United States, by an exhaustive discussion of innumerable results of observations showed that the latitude of every point on the Earth was subject to a double oscillation, one having a period of a year, the other of 427 days.

Notwithstanding the remarkable parallel between the growth of American astronomy and that of your city, one cannot but fear that if a foreign observer had been asked only half a dozen years ago at what point in the United States a great school of theoretical and practical astronomy, aided by an establishment for the exploration of the heavens, was likely to be established by the munificence of private citizens, he would have been wiser than most foreigners had he guessed Chicago. Had this place been suggested to him I fear he would have replied that were

it possible to utilize celestial knowledge in acquiring earthly wealth here would be the most promising seat for such a school. But he would need to have been a little wiser than his generation to reflect that wealth is at the base of all progress in knowledge and the liberal arts, that it is only when men are relieved from the necessity of devoting all their energies to the immediate wants of life that they can lead intellectual lives, and that we should therefore look to the most enterprising commercial center as the likeliest seat for a great scientific institution.

Now we have the school, and we have the Observatory, which we hope will in the near future do work that will cast luster on the name of its founder as well as on the astronomers who may be associated with it. You will, I am sure, pardon me if I make some suggestions on the subject of the future needs of the establishment. We want this newly founded institution to be a great success, to do work which shall show that the intellectual productiveness of your community will not be allowed to lag behind its material growth. The public is very apt to feel that when some munificent patron of science has mounted a great telescope under a suitable dome and supplied all the apparatus which the astronomer wants to use success is assured. But such is not the case. The most important requisite, one more difficult to command than telescopes or observatories, may still be wanting. A great telescope is of no use without a man at the end of it, and what the telescope may do depends more upon this appendage than upon the instrument itself. The place which telescopes and observatories have taken in astronomical history are by no means proportional to their dimensions. Many a great instrument has been a mere toy in the hands of its owner. Many a small one has become famous. Twenty years ago there was here in your own city a modest little instrument which, judged by its size, could not hold up its head with the great ones even of that day.

It was the private property of a young man holding no scientific position and scarcely known to the public. And yet that little telescope is today among the famous ones of the world,

having made memorable advances in the astronomy of double stars, and shown its owner to be a worthy successor of the Herschels and the Struves in that line of work. A hundred observers might have used the appliances of the Lick Observatory for a whole generation without finding the fifth satellite of Jupiter; without successfully photographing the cloud forms of the Milky Way; without discovering the extraordinary patches of nebulous light, nearly or quite invisible to the human eye, which fill some regions of the heavens.

When I was in Zurich last year I paid a visit to the little but not unknown observatory of its famous polytechnic school. The professor of astronomy was especially interested in the observations of the Sun with the aid of the spectroscope, and among the ingenious devices which he described, not the least interesting was the method of photographing the Sun by special rays of the spectrum which had been worked out at the Kenwood Observatory in Chicago. The Kenwood Observatory is not, I believe, in the eye of the public one of the noteworthy institutions of your city which every visitor is taken to see, and yet this invention has given it an important place in the science of our day.

Should you ask me what are the most hopeful features in the great establishment which you are now dedicating I would say that they are not alone to be found in the size of your unequaled telescope, nor in the cost of the outfit, but in the fact that your authorities have shown their appreciation of the requirements of success by adding to the material outfit of the establishment the three men whose works I have described.

Gentlemen of the trustees, allow me to commend to your fostering care the men at the end of the telescope. The constitution of the astronomer shows curious and interesting features. If he is destined to advance the science by works of real genius he must, like the poet, be born, not made. The born astronomer, when placed in command of a telescope, goes about using it as naturally and effectively as the babe avails itself of its mother's breast. He sees intuitively what less gifted men have to learn by long study and tedious experiment. He is moved

to celestial knowledge by a passion which dominates his nature. He can no more avoid doing astronomical work, whether in the line of observations or research, than the poet can chain his Pegasus to earth. I do not mean by this that education and training will be no use to him. They will certainly accelerate his early progress. If he is to become great on the mathematical side, not only must his genius have a bend in that direction, but he must have the means of pursuing his studies. And yet I have seen so many failures of men who had the best instruction, and so many successes of men who scarcely learned anything ot their teachers, that I sometimes ask whether the great American celestial mechanician of the twentieth century will be a graduate of a university or of the backwoods.

Is the man thus moved to the exploration of nature by an unconquerable passion more to be envied or pitied? In no other pursuit does success come with such certainty to him who deserves it. No life is so enjoyable as that whose energies are devoted to following out the inborn impulses of one's nature. The investigator of truth is little subject to the disappointments which await the ambitous man in other fields of activity. It is pleasant to be one of a brotherhood extending over the world, in which no rivalry exists except that which comes out of trying to do better work than anyone else, while mutual admiration stifles jealousy. And yet, with all these advantages, the experience of the astronomer may have its dark side. As he sees his field widening faster than he can advance he is impressed with the littleness of all that can be done in one short life. He feels the same want of successors to pursue his work that the founder of a dynasty may feel for heirs to occupy his throne. He has no desire to figure in history as a Napoleon of science whose conquests must terminate with his life. Even during his active career his work may be of such a kind as to require the coöperation of others and the active support of the public. If he is disappointed in commanding these requirements, if he finds neither coöperation nor support, if some great scheme to which he may have devoted much of his life

thus proves to be only a castle in the air, he may feel that nature has dealt hardly with him in not endowing him with passions like to those of other men.

In treating a theme of perennial interest one naturally tries to fancy what the future may have in store. If the traveler contemplating the ruins of some ancient city which in the long ago teemed with the life and activities of generations of men sees every stone instinct with emotion and the dust alive with memories of the past, may he not be similarly impressed when he feels that he is looking around upon a seat of future empire; a region where generations yet unborn may take a leading part in molding the history of the world? What may we not expect of that energy which in sixty years has transformed a straggling village into one of the world's great centers of commerce? May it not exercise a powerful influence on the destiny not only of the country but of the world? If so, shall the power thus to be exercised prove an agent of beneficence, diffusing light and life among nations, or shall it be the opposite?

The time must come ere long when wealth shall outgrow the field in which it can be profitably employed. In what direction shall its possessors then look? Shall they train a posterity which will so use its power as to make the world better that it has lived in it? Will the future heir to great wealth prefer the intellectual life to the life of pleasure?

We can have no more hopeful answer to these questions than the establishment of this great University in the very focus of the commercial activity of the West. Its connection with the institution we have been dedicating suggests some thoughts on science as a factor in that scheme of education best adapted to make the power of a wealthy community a benefit to the race at large. When we see what a factor science has been in our present civilization, how it has transformed the world and increased the means of human enjoyment by enabling men to apply the powers of nature to their own uses, it is not wonderful that it should claim the place in education hitherto held by classical studies. In the contest which has thus arisen I take no part but

that of a peacemaker, holding that it is as important to us to keep in touch with the traditions of our race and to cherish the thoughts which have come down to us through the centuries as it is to enjoy and utilize what the present has to offer us. Speaking from this point of view, I would point out the error of making the utilitarian applications of knowledge the main object in its pursuit. It is a historic fact that abstract science, science pursued without any utilitarian end, has been at the basis of our progress in the application of knowledge. If in the last century such men as Galvani and Volta had been moved by any other motive than love of penetrating the secrets of nature they would never have pursued the seemingly useless experiments they did, and the foundation of electrical science would not have been laid. Our present applications of electricity did not become possible until Ohm's mathematical laws of the electric current, which when first made known seemed little more than mathematical curiosities, had become the common property of inventors. Professional pride on the part of our own Henry led him, after making the discoveries which rendered the telegraph possible, to go no further in their application, and to live and die without receiving a dollar of the millions which the country has won through his agency.

In the spirit of scientific progress thus shown, we have patriotism in its highest form: a sentiment which does not seek to benefit the country at the expense of the world, but to benefit the world by means of one's country. Science has its competition, as keen as that which is the life of commerce. But its rivalries are over the question who shall contribute the most and the best to the sum total of knowledge, who shall give the most, not who shall take the most. Its animating spirit is love of truth. Its pride is to do the greatest good to the greatest number. It embraces not only the whole human race but all nature in its scope. The public spirit of which this city is the focus has made the desert blossom as the rose, and benefited humanity by the diffusion of the material products of the earth. Should you ask me how it is in the future to use its influence for the

benefit of humanity at large, I would say, look at the work now going on in these precincts, and study its spirit. Here are the agencies which will make "the voice of law and harmony of the world." Here is the love of country blended with the love of the race. Here the love of knowledge is as unconfined as your commercial enterprise. Let not your youth come hither merely to learn the forms of vertebrates and the properties of oxides, but rather to imbibe that catholic spirit which, animating their ever gracious energies, shall make the power they shall wield an agent of beneficence to all mankind.

THE AIM OF THE YERKES OBSERVATORY.[1]

By GEORGE E. HALE, Director.

IT gives me very great pleasure to extend to you all, on behalf of the members of the staff of the Yerkes Observatory, a most cordial welcome. The feeling of satisfaction which I share with my colleagues at seeing so many present is deepened by the peculiar circumstances under which we have come together. Removed from the neighborhood of great cities, and from the more populous regions of the United States, the Yerkes Observatory could hardly have hoped to draw hither so many well-known investigators. Realizing as we do the great distances many of you have come to favor us with your presence today, we assure you of our high appreciation of the honor thus done to the Observatory. The season and the place alike render difficult the provision of such entertainment as we would wish to offer. But all that we have is placed freely at your disposal, in the hope that the week may not be without some element of pleasure or profit to every one who has come to take part in these conferences.

I am sure that those who have watched, with an interest not confined to a single field, the recent parallel advances of astronomy and physics, will feel a peculiar sense of satisfaction in our gathering today. The fact that the programme of the conferences has attracted hither not only astronomers whose researches deal with all phases of their subject, but also physicists, fresh from the investigations of the laboratory, will indicate my meaning. If I mistake not the signs of the times, the Yerkes Observatory can render no better service to both astronomy and physics than to contribute, in such degree as its resources may allow, toward strengthening the good will and common interest which are ever tending to draw astronomers and physicists into closer

[1] Address delivered at the conferences held in connection with the dedication of the Yerkes Observatory, Oct. 19, 1897.

touch. During its three years of publication, the ASTROPHYSICAL JOURNAL has had the same end in view. The annual meetings of its editors, of late devoted mainly to the informal discussion of astrophysical investigations, have invariably been of great interest and value. Both physical and astronomical subjects have been considered equally appropriate for presentation, and the privilege of listening to discussions in which both sides of a question received attention has been greatly valued by those who have taken part in the meetings. In the pages of the JOURNAL one is likely to find a paper on radiation in a magnetic field in close proximity to an account of nebular photography or a discussion of stellar motion in the line of sight. For the scope of astrophysical work is far from narrow. In considering it we must remember that the problems it offers may be viewed in two ways. He who is primarily an astronomer, when examining the photographic spectrum of some remarkable variable star, will be inclined to seek in the shifting dark and bright lines evidence of orbital motion, or indications that may lead to the discovery of the nature of the system. The physicist may find himself equally interested in the photograph, but in a different way. The peculiarities of the spectral lines may have to him the highest significance in connection with some of his own molecular studies. The special conditions of temperature or pressure needed to bring out certain series of lines, known through theoretical investigation perhaps, but not to be developed by any familiar laboratory process, may actually exist in the atmosphere of this distant star. To the physicist, and even to the chemist, this fiery crucible may afford the means of performing experiments far beyond the scope of terrestrial laboratories. In such a case the spectroscope might well be considered the essential instrument of research, the telescope playing a lesser, but nevertheless a very important rôle. It is sometimes interesting to remember that from certain points of view a telescope may not improperly be defined as an instrument for forming an image of a celestial object on the slit of a spectroscope.

Hydrogen gas affords a most interesting illustration of what has just been said. When first studied in the laboratory its spectrum showed four lines in the visible region, and none in the ultra-violet. Then came the pioneer work of Sir William Huggins in photographing the spectra of the stars. He at once found from investigations of Sirius and other white stars that the four bright lines represented only the first few terms of a beautiful rythmical series stretching far into the ultra-violet. The regularity of the grouping was such as to compel belief in the physical continuity of the series, in spite of the failure of the ultra-violet lines to make their appearance in the vacuum tube. Almost simultaneously with Sir William Huggins' discovery of the stellar series, the gas was made to emit these radiations in the laboratory for the first time. In 1885, after the wave-lengths of the new lines had been carefully measured by Cornu and others, it was found by Balmer that the wave-frequencies are harmonically related, in accordance with a simple formula. In 1868 the visible members of the series had been observed in the spectrum of the solar chromosphere, and in 1891 the ultra-violet members were found by the aid of photography. It was still a mystery, however, why the spectrum of hydrogen should apparently contain only a single series of lines, for the spectra of most of the other elements have been shown by Kayser and Runge to give two or more such series. It is only in the present year that a second series has been found, not yet in the laboratory, but in the spectrum of an inconspicuous southern star, which in all probability would have retained its secret for many years longer, had it not been for Professor Pickering's extensive explorations with the objective prism as a part of the Henry Draper Memorial. Two series thus being known, it might be thought possible to compute the wave-lengths of lines in a third by taking advantage of the important relation discovered by Rydberg, and independently by Schuster and Balmer. This has recently been done by Dr. Rydberg himself, and in the October number of the ASTROPHYSICAL JOURNAL may be found the computed wave-lengths of the lines of the hitherto unknown princi-

pal series. Thanks once more to Professor Pickering's work, the theoretical results find complete confirmation. The faint star *H. P.* 1311 has in its photographed spectrum a bright line at wave-length 4688, while the computed wave-length of the first line in the principal series of hydrogen is 4687.88. There can be little doubt that the line 4687 in the spectra of certain planetary nebulæ, observed many years ago by Sir William Huggins, and more recently by Campbell and others, is the same hydrogen line. Rydberg's computed wave-lengths place the other lines far in the ultra-violet, where atmospheric absorption renders them beyond the reach of observation. It now remains for the physicist to reproduce in the laboratory the special conditions which obtain in the atmospheres of these stars, in order that the two new series may be developed by artificial means.

Illustrations similar to this might easily be multiplied, particularly in the very interesting case of helium. But it is surely unnecessary to dwell longer upon the importance of astrophysical work, or to insist further upon the desirability of bringing about its harmonious development on both the astronomical and physical sides. I must not fail to add, however, that the best results, and the most rapid development of both phases of the subject, are likely to follow when the two are worked out together. Let us suppose that the astrophysicist, while investigating the spectrum of a Sun-spot, or a nebula, or a star, finds some remarkable peculiarity not to be accounted for by appealing to the established results of physics. He may be content to call the attention of physicists to the phenomenon, in the hope that some of them may be ready to drop their own investigations in order to assist in answering the question. But he would certainly regard it as more satisfactory to have at hand a well-equipped laboratory, in which just such experiments as he might wish to make could be performed at any time. To take a definite example, he might find in the spectrum of a Sun-spot a line which for various reasons could be identified as due to a certain element, but which was displaced from its normal position. Now it is known that spectral lines may be displaced in two

ways—(1) by motion in the line of sight; (2) by the effect of pressure. If the displacement is toward the red it may be due to either of these causes. In this connection it becomes important to ascertain just how much pressure is needed to shift the line the measured amount. And it might be hardly less interesting to examine the appearance of the line in order to see how its condition is altered by the pressure to which it is subjected. As for the displacement due to the pressure, we might be fortunate enough to find it in Dr. Humphreys' valuable tables, published in the October ASTROPHYSICAL JOURNAL; but as of necessity no very great number of lines in any one spectrum have been examined by Dr. Humphreys, the chances would be against our finding the desired shift. It may be a long time before more extensive investigations on pressure shifts are made, and one would not like to be compelled to wait for an indefinite period in order to get at a possible interpretation of his results. It is obvious that if the observer had at his command a large spectroscope and a pressure arc mounted ready for immediate use, it would be a comparatively simple matter to experimentally determine the amount of shift for any line at any attainable pressure. The observer would then have under his eyes a phenomenon which he could compare directly with what he had seen or photographed in the Sun-spot. There would be not only the advantage of a saving of time, but in addition to this, and perhaps even more important, would be the advantage which must result from an intimate acquaintance with both the solar and terrestrial phenomena derived from observations made by a single observer.

It seems unnecessary to dwell further upon this point. In it I think we have complete justification for equipping a large observatory in which astrophysical observations are to be made, with complete physical laboratories. This is not a new thing, as you all know. We have a most brilliant example in the case of the Astrophysical Observatory at Potsdam of what may be done in this direction. But in the United States, less for lack of means than for lack of inclination, such observatories have

hitherto been few. In discussing such a matter as this we must not forget the remarkable pioneer work of Rutherfurd and Draper, whose observatories were at the same time laboratories, and whose investigations were almost as important to physics as to astronomy. Nor must we forget the Allegheny Observatory, where Professors Langley, Keeler, and Very have obtained such valuable results in both celestial and terrestrial spectroscopy, nor the Smithsonian Observatory, where the traditions of the Allegheny Observatory are being continued. It has seemed to me, however, from the time when the Yerkes Observatory first acquired a prospective existence, that there was good reason to give further expression to this idea. Accordingly this Observatory has been planned in such a way as to give opportunity for various physical investigations, interesting and valuable in themselves, and also in their connection with astrophysical work.

While the plans were being made I was fortunate enough to have frequent access to the Potsdam Observatory, and from an acquaintance with its arrangement acquired at that time, as well as from kindly suggestions from Director Vogel and other members of the staff, many ideas which have been embodied in this Observatory were obtained. Valuable suggestions received from other astronomers and physicists have also been adopted. I will not burden you with a detailed description of the building. It is before your eyes and ready for your inspection. The equipment, it is true, is still far from complete, and much remains to be done to put the Observatory in working order in all its departments.

But I must point out that these departments are intended to include not only astrophysical work, but other classes of astronomical investigation as well. In completing the equipment it will be our aim to secure an observatory in which any phase of an astronomical, astrophysical or related physical problem can be investigated. It is very far from our desire, in giving such expression as will be given here to astrophysical work, to in any way crowd out the long established traditions of the astronomy of position. On the contrary, it is

fully recognized that questions of position and of motion are equally important with questions of constitution and physical condition. If we are at work upon a star we must not be content to investigate its spectrum, to determine the chemical composition of its atmosphere, the conditions of temperature and pressure that exist in it, and the motion of the star in the line of sight. Surely there is no fundamental peculiarity that makes the component of the motion which lies in the sight-line more interesting than the component at right angles to it. Thus there may well be associated with the astrophysical investigations just referred to researches on the absolute position of the star and upon its proper motion. Parallax investigations may advantageously be carried on simultaneously, and in fact we can omit from consideration none of the methods or problems of the astronomy of position. It is hoped, then, that when instruments and staff are sufficiently large to permit investigations to be undertaken in these various fields of research, that astronomical, astrophysical and physical problems may receive the attention they deserve.

But so ambitious a programme is not to be developed in the first few years of the Observatory's history. While our staff is small and our instruments comparatively few, we must confine our attention to those fields where our equipment and the special tastes of our observers give promise of the best results. To determine, then, the best fields of investigation to be pursued at the present time, it seems to me that we should consider the special qualities of the large telescope. In subjecting this instrument to a series of tests we have found that these qualities are just what we might have expected them to be. You may perhaps be interested to know what these tests have been, and how they have resulted. On account of its great size and excellence, and the important work which has been done with it, the Lick telescope has naturally served as our standard in all comparisons.

The resolving power of the object-glass has been tested by Professors Burnham and Barnard by observing very close

double stars. Such an object as Kappa Pegasi, the components of which are now less than a tenth of a second apart, was clearly and beautifully seen as an elongated disk under a power of 2080. As the theoretical resolving power is about one-tenth of a second, this observation could not have been more satisfactory. Close double stars were subsequently seen by Professor Barnard with a power of 3750 so well defined that micrometrical measurements could easily have been made. As it is probable that so high a power as this has not previously been advantageously used with any telescope, it would seem that no better proof could be offered of the excellence of the object-glass. I should also mention that Professor Barnard has picked up four or five very close new double stars. Incidentally it may be added that the atmospheric conditions which would permit the use of a power of 3750 must have been of the very best. Of course such powers cannot be used often; but Professor Barnard has found that the best nights here are fully as good as the best nights at the Lick Observatory, though the average night seeing is not as good as it is at Mt. Hamilton. Of the day seeing I shall speak further on.

As for the light-gathering power of the telescope, this seems to be quite as great as the large aperture would lead one to expect. Perhaps the best proof of this is afforded by Professor Barnard's observation of a new companion to Vega, which had not been seen with the Lick telescope. The distance of this object from Vega is too great to permit us to suppose that there is any physical connection between the two bodies, and the discovery is therefore to be regarded as of no special astronomical significance. But it does afford excellent evidence of the light-gathering power of the object-glass, as well as the perfection of polish, for without this latter quality so faint an object would not be visible in the immediate neighborhood of so bright a star.

Nebulæ, too, are beautifully seen with the Yerkes telescope. Professor Barnard has examined many of these objects with which he had become familiar at Mt. Hamilton, and he assures

me that he now sees them better than he could see them with the Lick telescope. Without making any special search for them he has already discovered some twenty new nebulæ. Hind's remarkable variable nebula in Taurus has recently been seen here by Professor Barnard, although it was invisible when last looked for at Mt. Hamilton. It may be that the present visibility is due to an increased brightness, but Professor Barnard is inclined to attribute it to the instrument with which the observations were made.

I have obtained further proof of the great light-gathering power of the object-glass in some preliminary work on stellar spectra. The star images are extremely bright and the exposure times in making photographs are correspondingly short.

Another peculiarity of the Yerkes telescope, which Professor Barnard finds to be of the highest importance in his micrometrical work, is the remarkable steadiness of the mounting. A reference to some of Professor Barnard's measures will illustrate this better than any mere description could do. The difference of declination between Atlas and Pleione was recently measured on five successive nights (the telescope being in motion) with the following results: Aug. 27, 300″.65; Aug. 29, 300″.60; Sept. 2, 300″.66; Sept. 3, 300″.72; Sept, 4, 300″.67. It will be noticed that the distance is a large one to measure with an ordinary filar micrometer, and yet the greatest difference between any two observations made on different nights amounts to only 0″.12. It will be interesting to compare this with some of Professor Barnard's previous measures which he had always considered very satisfactory. In 1893 he measured the distance between Nova Aurigae and a neighboring star with the Lick telescope. Measures made on thirty-two nights gave a distance of about seventy-four seconds, the greatest difference between any two observations made on different nights amounting to 0″.60. Five successive observations are given for comparison with the more recent measures: 74″.73, 74″.53, 74″.38, 74″.33, 74″.69. The difference in the character of the objects, which may affect the results to some extent, should, however be taken into

consideration. Professor Barnard has made with the Yerkes telescope a number of micrometrical observations of the satellite of Neptune, the planetary nebula *N. G. C.* 7662, and other objects, and in every case has found his measures to be of great precision.

The great object-glass has received another and a different test in my own observations of the Sun. Fortunately for this work the atmospheric conditions enjoyed here in the day time are exceptionally good. For instance, I have seen the details in the solar chromosphere and prominences beautifully defined under a power as high as 600, which would usually be regarded as excessive for such work. But the special advantages of this satisfactory combination of good atmospheric and instrumental conditions have been most clearly emphasized in observations of the spectrum of the Sun's limb. It has been found that the quiet chromosphere gives many bright lines not hitherto recorded, even in the case of violent eruptions. Among these we may probably include the green fluting of carbon. So many new lines have already been seen that it seems desirable to undertake a complete revision of the chromospheric spectrum.

The success of these various tests convinces me of the desirability of carrying into effect the plan of work mapped out for this Observatory in 1892. This includes various classes of solar investigation ; micrometrical observations of double stars, planets, satellites, nebulæ, comets, etc ; parallax work ; photographic studies of stellar spectra, including determinations of motion in the line of sight ; and various physical researches in the laboratories. Miss Bruce's recent gift of a ten-inch photographic telescope will render possible additional photographic observations of many celestial phenomena. Later, when increased staff and instrumental equipment permit, it may become possible to enter other fields. But for the present we may profitably confine our attention to the investigations just enumerated.

I venture to invite your special attention to the instrument and optical shops of the Observatory, for I believe them to be a most important adjunct in our work. With the facilities here

provided it is possible to construct the various pieces of special apparatus which are constantly in demand, particularly in astrophysical and physical work. At the present time you will see in process of construction a 24-inch heliostat, an equatorial mounting for a 24-inch reflecting telescope, a ruling machine for optical gratings, a solar spectroscope and spectroheliograph for the 40-inch telescope, and a 60-inch mirror for stellar spectroscopic work. In this connection I cannot omit to express my appreciation of the services rendered by Professor Wadsworth in designing instruments, and supervising their construction. Mr. Ritchey has done valuable work, not only in making optical surfaces, but also in designing the large grinding machine, a considerable part of which he has built with his own hands. Much credit for the excellent work of the instrument shop is due to Messrs. Lorenz, Mors, and Kathan, who have proved themselves most efficient. In fact, not only in the shops, to which I have alluded on account of the special place they occupy in this Observatory, but in all the phases of our work of preparation, each member of the staff has fully done his part.

I wish to acknowledge at this time the obligation of the Yerkes Observatory to the many institutions and individuals whose gifts of books have enriched our library. For these liberal donations we return our warmest thanks. Nor must we forget those who have contributed so much to the success of these conferences by loaning instruments for the demonstrations. From its very inception the Observatory has received the support of men of science in all parts of the world. For all these evidences of interest in our work we are deeply grateful.

The time has now come when we may turn from anticipation to realization, from planning to performance. We have before us the serious task of carrying into execution the investigations which have been projected. It is the ambition of the members of the Observatory staff that the work to be done here shall acquire a reputation for thorough reliability. We mean to do all we can to discourage sensationalism, the evils of which

have been only too apparent in recent astronomical literature. Finally, we share the hope expressed by Mr. Yerkes that this Observatory may take its place among sister institutions, not as a rival, but as one which would gladly do its part in the advancement of a common cause.

SPECTROSCOPIC NOTES.[1]

By Sir William and Lady Huggins.

ON THE SPECTRA OF THE STARS IN THE TRAPEZIUM OF THE GREAT NEBULA OF ORION.

In our original photographs of the spectrum of the Great Nebula of Orion, including that of the Trapezium stars,[2] we observed and measured in the continuous spectra of these stars a number of bright lines which appeared to extend into the nebula on both sides, and which consequently justified us in concluding that these stars are, or had been, physically connected with the nebula itself.

These bright lines, however, have not been recorded as present in the photographs which have been taken subsequently by other observers. For this reason we thought it desirable to attempt to reproduce the small original negatives by a method of direct enlargment. These enlargements show the bright lines, of which measures were given, together with the blotchy character of the chief nebular lines, and the other points to which attention was directed in our papers.

In consequence, however, of the long exposure which was given to the plates in order to bring out the fainter nebular lines, the continuous spectra of the Trapezium stars were so much over-exposed as to cause the dark lines to disappear, and so these were not observed by us in these early photographs.

Copies of the enlargements accompany these notes. If they cannot be succesfully reproduced as illustrations, I should be glad for them to be placed in the Yerkes Observatory for reference.[3]

During the last three years, by means of the newer form of my reflection-slit, we have succeeded in obtaining separate pho-

[1] Read at the conferences held in connection with the dedication of the Yerkes Observatory, Oct. 18, 1897.

[2] *Proc. R. S.*, **46**, 40; **48**, 213.

[3] It unfortunately seems to be impossible to successfully reproduce these photographs by the means at our disposal.—Eds.

tographs of the three brightest stars of the Trapezium. The true character of these spectra was observed by us in a photograph taken in 1894, but we have put off publishing an account of them in the hope of being able to obtain more complete results. The unusual bad weather during the last two winters, and some other unavoidable circumstances, have made it impossible for us to take photographs as rich in detail as it would be easily possible to get under more favorable circumstances. We think that it would be desirable now, without any further delay, to publish a short preliminary note about them.

The photograph of 1894, together with photographs taken subsequently in 1895, 1896, and 1897, show that we have to do with a spectrum, which by the peculiar association of bright lines and dark lines suggests the class to which β Lyrae belongs, and possibly to some extent that of Nova Aurigae soon after its first appearance, though it differs from the spectra of both these stars in many points.

In the spectrum of the principal star of the Trapezium the hydrogen series can be traced as far as $H\pi$. The calcium line K is very thin, and appears to be near, or upon, a bright radiation, which may or may not be associated with it. The spectrum is rich throughout in absorption lines and in bright radiations, with the special character strongly marked of bright bands associated with corresponding dark absorption lines. The dark lines are not usually symmetrically placed upon the bright bands, but in most cases the bright band is chiefly, or altogether, on one side of the corresponding dark line.

A comparison of the photographs of the same star taken from 1894 to 1897 leaves no doubt in our minds that the relative positions of the dark and of the reversed bands appear to be subject to change. For example, in the 1894 photograph, the bright hydrogen radiation was mainly on the blue side of the dark band, while in 1897 it seems to be chiefly on the other side of the absorption line.

Bright lines are present in the spectrum of this star about the place in the spectrum where the bright lines were measured

by us in our early photographs. If the weather favors us, we confidently hope to take photographs which will permit of the measurements of these lines under considerable magnification.

The spectra of the second and of the third star are similar in character to that of the first.

It does not come within the scope of this purely preliminary note, and indeed it would be premature, to attempt any discussion of the possible physical conditions prevailing in these stars, and of their probable evolutional connection with the nebula itself.

Enlargements from the original negatives of the spectra of these stars are sent herewith.

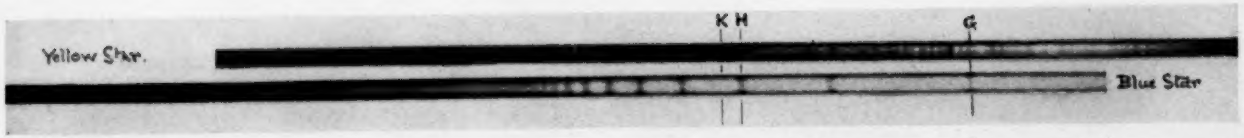
ON THE SPECTRA OF THE COLORED COMPONENTS OF β CYGNI.

This star is a fine example of a class of double stars of which the components are strongly contrasted in color. It is not necessary to say that the colors are real, though, no doubt, the impression of difference of color which the eye receives is heightened by the effect of contrast, through the nearness of the stars.

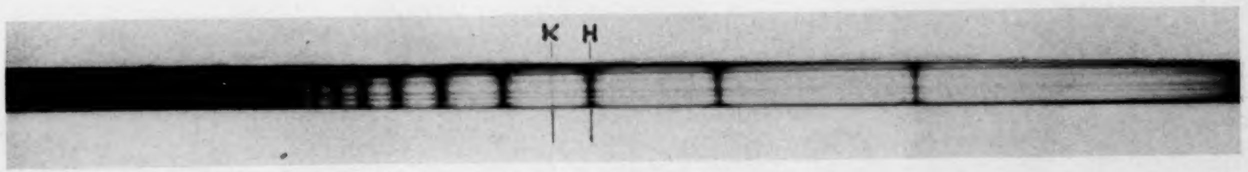
In 1864, I pointed out, as an obvious corollary from the observations of the spectra of stars by myself and Dr. Miller, that the origin of the contrasted colors in pairs of stars is to be sought for in the nature and the condition of the substances by which the light is radiated and absorbed. This view was confirmed by us by the direct observation by eye of the spectra of the components of α Herculis and of β Cygni.

The study of the physical conditions, as revealed by their spectra, of the colored components in pairs of stars has now become of great interest through Dr. See's theory of the tidal evolution of binary stars. On this theory we must assume both stars to be of the same age, and to be composed of the same substances, though not necessarily in the same proportions. The spectra of such pairs of stars should then indicate the relative evolutional stages which the components had severally reached; the life-history of a star being passed through more rapidly, and so the several stages coming in at an earlier date,

PLATE XIX.



SPECTRA OF THE COMPONENTS OF β CYGNI.



SPECTRUM OF α LYRAE.

it may be presumed, in the case of the component which has the smaller mass.

A similar reasoning would lead to the conclusion that the pairs which have reached a more advanced type of spectrum came into being, as double stars, at an earlier date than those of which the spectra of both components are still in an early stage.

We are able to point out a remarkable example of a relatively late separation of the original mass in the case of Cor Caroli. Our photographs show that the brighter component is still in the white-star stage, with the calcium line K very thin; while the less bright star belongs also to the same type, but with a marked increase in the thickness of K, which, however, still remains thinner than H.

On the other hand, the advanced condition, shown by the spectra of both components of γ Leonis, would put back the coming into existence of this pair by evolutional separation, to a much earlier time; unless, indeed, the total mass of matter in both stars is much smaller than it is in Cor Caroli.

In α Herculis the spectrum of the brighter star has reached the Class III *a*.

To return to the relative evolutional progress of the components of one system; here we should expect the brighter star to show an earlier type of spectrum. Now, such is not the case in the spectra of the strongly contrasted colored components of β Cygni, of which enlargements are herewith presented (Plate XIX).

It is the spectrum of the feebler star, of the 5.3 mag. only, which is still of the white-star type, while the brighter star of the 3 mag. gives a spectrum which shows that it is well on the way towards the solar stage, though the calcium line K is still less broad than the calcium-hydrogen line H. The visual colors of the two components correspond to these stages. The small star having the bluish-white color characterizing the stars which we regard as in an early stage, while the brighter star is yellow, resulting from greater enfeeblement of the blue by incoming absorption.

It is true that in this pair no relative motion has been detected, and that the distance apart of the stars is over the arbitrary limit assigned by Struve to true double stars, but it seems to me more than probable that we ought to regard them as evolutionally connected.

We have, therefore, to face the apparent anomaly that it is the "larger" star which is in the more advanced stage of development. It may reasonably be suggested that we really know nothing of the true relative masses of the stars, and that we have no certain ground for assuming that the brighter star is actually the larger one.

I have pointed out elsewhere[1] that the brightness of a star, that is the luminous energy radiated from it, depends upon several conditions, and must be largely affected by the nature and the conditions of the substances by which the light is chiefly emitted, as well as by the amount and the conditions of the absorbent atmosphere through which it has to pass. It is conceivable, therefore, that the blue star, though less brilliant, is of greater size, and so remains still in an earlier evolutional stage.

Another way of looking at the problem is perhaps possible. May it be that the effect of great mass on surface density, together with the working of Lane's law, by which the temperature of a condensing gaseous mass, so long as it is subject to the laws of a purely gaseous body, will continue to rise, will favor in such stars the coming in of a solar type of spectrum at a somewhat relative earlier time?

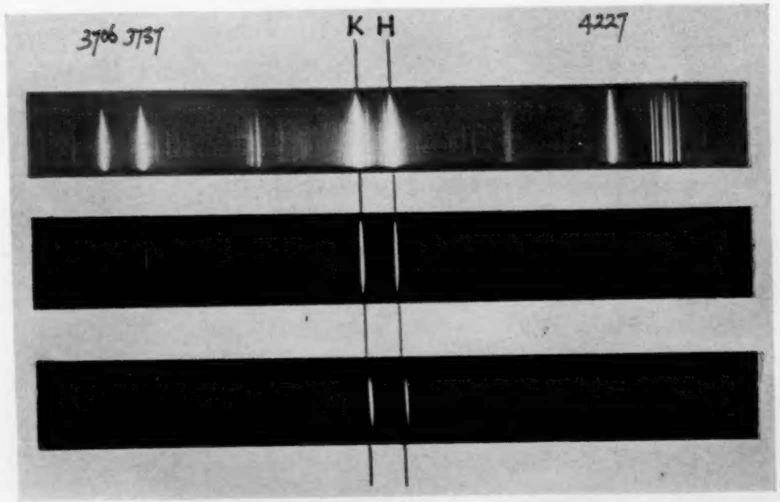
ON THE ULTRA-VIOLET SPECTRA OF α LYRAE, AND OF ARCTURUS.

I take this opportunity of sending a photograph of the spectrum of α Lyrae, which shows with great completeness the lines of the hydrogen series. In the negative sixteen lines can be counted beyond $H\epsilon$, so bringing the series up to $H\phi$.

As the exposure was timed for the ultra-violet part of the hydrogen series, the blue part of the spectrum has been over-

[1] Address Brit. Assoc. 1891, pp. 15, 16.

PLATE XX.



SPECTRUM OF CALCIUM.

exposed for the crowd of fine dark lines between the hydrogen bands, which, in consequence, are only faintly visible. On the other hand the extreme ultra-violet has been greatly under-exposed, though it may still be faintly traced as far as $\lambda 3250$. A longer exposure would be needed to bring out this part of the spectrum strongly, and as far as $\lambda 2970$, to which we were able to trace the star's spectrum in a photograph taken in 1888.[1]

This photographic difficulty has been got over in the case of the spectrum of Arcturus by placing together parts of three photographs taken with different lengths of exposure, so as to give to each part of the spectrum an exposure suitable for it. On account of the great range of wave-length covered by these spectra a very moderate degree of enlargement only, has been employed.

EFFECT OF DENSITY ON THE SPECTRUM OF CALCIUM.

The three photographs (Plate XX) show in a very striking way the effect of great tenuousness of calcium vapor in reducing the spectrum to the two lines H and K, and the greater strength of K relatively to H, as the tenuity is increased.

No. 1 shows the spectrum with a feeble spark between electrodes of metallic calcium.

No. 2. Spectrum of a similar spark between platinum electrodes, moistened with a weak solution of fluoride of calcium, and then well washed. The line at 4227 has all but disappeared, but the more refrangible pair faintly present, 3706 being stronger than 3737.

No. 3. Similar spark between platinum eloctrodes touched with moistened magnesia which contained a trace, as an impurity, of lime. H and K strong and alone. A faint trace of the magnesium triplet on the more refrangible side of K. The line K distinctly stronger than H. Both lines thin and defined.

TULSE HILL OBSERVATORY,
London, Sept. 29, 1897.

[1] *Proc. R. Soc.*, **46**, 133.

NEW INVESTIGATIONS OF THE SPECTRUM OF β LYRAE.

By A. Bélopolsky.

My investigations of this star in 1892 (*Bull de l'Acad. de S. Pétersbourg*), based on spectrograms of the region D–$H\gamma$, have shown that almost all the spectral lines vary with the light of the star, but that the true form of the dark and bright lines can hardly ever be determined, because they are always superposed.

The dark line of magnesium $\lambda = 4482$ seems to be the only one which preserves its form; its wave-length was determined, but on account of the fact that this line is found at the extremity of the spectrum, and also because of insufficient dispersion and a lack of suitable artificial lines, no decisive conclusions could be based upon these determinations. It was necessary to wait until I had at my disposal more powerful optical apparatus than that used in the earlier work. It is only at the present time (summer of 1897) that this desire has been realized.

Our large refractor now possesses a correcting lens for the actinic rays, and our large spectrograph with two Halle prisms has been supplied with a large collimator. Thanks to these two arrangements I have been able to secure spectra of stars to the 4.5 magnitude without prolonging the time of exposure beyond an hour; and I have undertaken to make a new collection of spectrograms of β Lyrae with iron lines for comparison. Between June 20 and August 2, when it was necessary to interrupt my observations on account of important repairs undertaken in the large dome, I obtained twenty-six spectrograms corresponding to all the phases of brightness.

Measures of the line 4482 were made according to a method described in my article on the spectrum of η Aquilae (see *Mem. Spettr. Ital.*) by means of the artificial lines 4384, 4405, 4415, and 4529, and a solar spectrogram which was superposed during

the measures on the spectrogram of the star. A microscope magnifying fifteen diameters was employed.

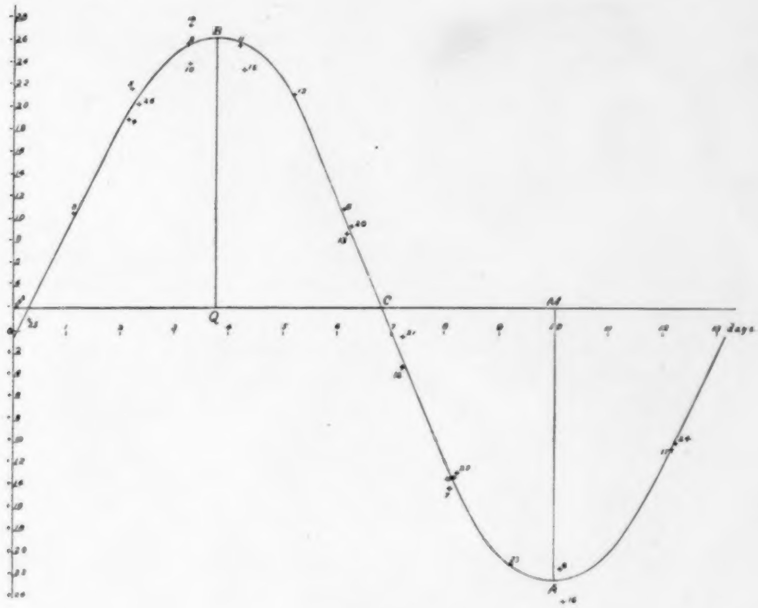


FIG. 1.

In order to give an idea of the character of the line 4482 and its surroundings I add a description of this part of the spectrum. None of the other lines can be utilized, and for this reason I have omitted them from the list. The descriptions are based upon an arrangement of the spectrograms according to epochs counted from the principal minimum (see the curve in Fig. 1).

1897

June 22, No. 2, $\lambda = 447$, dark, sharp; a very distinct bright line on the red side; $\lambda = 448$, broad, diffuse, dark; a bright line on the violet side; on account of the contrast there seems to be another dark line between the lines 447 and 448.

July 31, No. 25, $\lambda = 447$, dark, distinct, with a bright line on the red side; $\lambda = 448$, dark, sharp, single.

June 23, No. 3, $\lambda = 447$, dark, very strong, a very brilliant bright line on the red side ; $\lambda = 448$, dark, broad, very diffuse.

June 24, Nos. 4 and 5, $\lambda = 447$, dark, sharp ; a bright line on the violet side ; $\lambda = 448$, dark, sharp ; narrower than in the preceding plate.

August 2, No. 26, $\lambda = 447$, dark, sharp, with a maximum ; bright line lacking ; $\lambda = 448$, dark, sharp, very narrow.

July 8, Nos. 9 and 10, $\lambda = 447$, dark, sharp, very narrow ; $\lambda = 448$, dark, broader than in the preceding plate. The background of continuous spectrum between 447 and 448 seems to be bright.

July 21, No. 18, $\lambda = 447$, dark, narrow ; $\lambda = 448$, dark, sharp, very narrow ; traces of a bright line on the violet side.

July 9, No. 11, $\lambda = 447$, dark, very faint ; it is suspected that the spectrum contains many faint dark lines ; $\lambda = 448$, dark, sharp ; a bright line on the violet side.

July 10, No. 12, $\lambda = 447$, neither dark nor bright ; $\lambda = 448$, dark, very sharp ; perhaps a faint bright line on the violet side.

July 22, No. 19, $\lambda = 447$, dark, very faint ; bright line lacking ; $\lambda = 448$, dark, sharp ; a faint bright line on the violet side.

June 28, No . 6, $\lambda = 447$, dark, sharp ; a bright line on the violet side. $\lambda = 448$, dark, sharp ; a broad, bright line fills the entire space between 447 and 448.

July 24, No. 20, $\lambda = 447$, dark, sharp ; two bright lines on the violet side ; the one near the dark line is brighter than the other ; $\lambda = 448$, dark, distinct ; bright line altogether lacking.

July 11, No. 13, $\lambda = 447$, a hazy, dark line ; on the violet side a distinct bright line ; there is also one on the red side, but it is less distinct ; $\lambda=448$, dark, sharp ; bright line lacking.

July 12, No. 10, $\lambda = 447$, dark, pretty faint ; traces of a bright line ; $\lambda = 448$, dark, sharp.

July 25, No. 21, $\lambda = 447$, dark, pretty faint ; in the middle of a bright line ; $\lambda = 448$, dark, very sharp ; this spectrogram contains a number of very delicate dark and bright lines, particularly in the part of the spectrum between 448 and F.

June 30, No. 7, $\lambda = 447$, the dark line is lacking, but a broad dark band, with two very faint maxima of intensity, is present ; $\lambda = 448$, dark, sharp.

July 13, No. 15, $\lambda = 447$, two dark lines, very faint, which are perhaps due to the contrast between certain bright lines ; $\lambda = 448$, dark, distinct.

July 26, No. 22, $\lambda = 447$, it is clearly seen that the two dark lines are due to contrast between three bright lines ; the bright line which is in the middle is the brightest and narrowest. Its position is nearer the red side ;

$\lambda = 448$, dark, sharp; a bright line on the red side. This spectrogram contains many bright lines, *e. g.*, in the region $\lambda = 455$, where five are easily seen; further on there are others.

July 27, No. 23, $\lambda = 447$, two dark lines have become visible between the bright lines. The bright line which separates them is very brilliant; $\lambda = 448$ dark, sharp; possibly the edges are bright. On this spectrogram there are many dark lines, particularly in the region $\lambda = 455$.

July 2, No. 8, $\lambda = 447$, two distinct dark lines and two pretty strong bright ones. The dark line which lies between the bright lines is sharper than the other; $\lambda = 448$, dark, sharp. Several very faint lines are visible.

July 15, No. 16, $\lambda = 447$, dark, sharp; the edges are bright. There is also a second dark line on the red side; $\lambda = 448$, dark, pretty faint.

June 20, No. 1, $\lambda = 447$, dark, distinct, narrow; the violet edge is bright; $\lambda = 448$, dark, sharp.

July 17, No. 17, $\lambda = 447$, a complicated appearance; a narrow bright line on the violet edge of a broad dark band. Near the other edge a second narrow bright line appears in this band. The space between this last and the red edge appears like an isolated dark line; $\lambda = 448$, similar to the line 447, but all the parts are closer together, in such a way as to give the appearance of a single sharp, dark line with bright edges; that on the red side is brighter than the other; there is also in the neighborhood a pretty faint, dark line.

July 30, No. 24, $\lambda = 447$, this resembles the preceding spectrogram, but is not so sharp. The second bright line is broader than on the preceding spectrogram, and is situated nearly in the center of the dark band; $\lambda = 448$, dark, sharp.

This description affords sufficient support to the opinion already expressed that the dark line at $\lambda 4482$ changes but little in appearance, while the lines 447, $H\gamma$ and F (see my 1892 investigations) undergo great changes. However, the measures of the above mentioned line can give no very great precision because of certain peculiarities in its form.

I give below the results of the measures of the line at $\lambda 4482$ referred to a solar spectrogram. Let d_1 be the difference between the readings on the micrometer head for settings on the artificial lines and the corresponding solar lines; d_2 the difference between the settings on the line at $\lambda 4482$ in the stellar and solar spectra. The sum $d_1 + d_2$ gives the displacement of the line at $\lambda 4482$ expressed in parts of the revolution of the screw.

1897.

June 20

λ	d_1
4529	−0.275
4495	−0.256
4476	−0.223
4467	−0.193
4415	−0.176

For

$\lambda = 4482 \quad d_1 = -0.233$

$d_2 = +0.744$

Displacement = +0.511

June 22

λ	d_1
4529	−0.049
4415	−0.048
4405	−0.028

For

$\lambda = 4482, \; d_1 = -0.044$

$d_2 = -0.049$

Displacem't = −0.093

June 23

λ	d_1
4529	+0.149
4467	+0.127
4415	+0.091

For

$\lambda = 4482, \; d_1 = +0.125$

$d_2 = -0.450$

Displacem't = −0.325

June 24, 1st sp.

λ	d_1
4529	+0.368
4405	+0.345
4384	+0.363

For

$\lambda = 4482, \; d_1 = +0.364$

$d_2 = -0.931$

Displacem't = −0.567

June 28

λ	d_1
4529	+0.237
4405	+0.152
4384	+0.148

For

$\lambda = 4482, \; d_1 = +0.198$

$d_2 = -0.533$

Displacem't = −0.335

June 30

λ	d_1
4529	+0.260
4468	+0.202
4415	+0.197
4384	+0.165

For

$\lambda = 4482, \; d_1 = +0.218$

$d_2 = +0.184$

Displacem't = +0.402

July 2

λ	d_1
4529	+0.351
4415	+0.304
4384	+0.283

For

$\lambda = 4482, \; d_1 = +0.320$

$d_2 = +0.294$

Displacem't = +0.614

July 8, 1st sp.

λ	d_1
4529	−0.303
4415	−0.302
4405	−0.340
4384	−0.337

For

$\lambda = 4482, \; d_1 = -0.308$

$d_2 = -0.451$

Displacem't = −0.759

July 8, 2d measure

λ	d_1
4529	−0.258
4405	−0.299
4384	−0.313

For

$\lambda = 4482, \; d_1 = -0.270$

$d_2 = -0.473$

Displacem't = −0.743

July 8, 2d sp.

λ	d_1
4529	−0.244
4405	−0.290
4384	−0.307

For

$\lambda = 4482, \; d_1 = -0.257$

$d_2 = -0.444$

Displacem't = −0.701

June 24, 2d sp.

λ	d_1
4529	−0.212
4415	−0.224
4384	−0.218

For

$\lambda = 4482,\ d_1 = -0.217$

$d_2 = -0.432$

Displacem't = −0.649

July 17

λ	d_1
4529	+0.312
4415	+0.292
4405	+0.291
4384	+0.296

For

$\lambda = 4482,\ d_1 = +0.304$

$d_2 = -0.019$

Displacem't = +0.285

July 17, 2d measure

λ	d_1
4529	−0.157
4415	0.136
4405	0.140

For

$\lambda = 4482,\ d_1 = -0.149$

$d_2 = +0.483$

Displacem't = +0.334

July 21

λ	d_1
4529	−0.091
4415	0.046
4405	0.059
4384	0.078

For

$\lambda = 4482,\ d_1 = -0.061$

$d_2 = -0.726$

Displacem't = −0.787

July 9

λ	d_0
4529	+0.373
4405	+0.347
4384	+0.333

For

$\lambda = 4482,\ d_1 = +0.364$

$d_2 = -1.109$

Displacem't = −0.745

July 10

λ	d_1
4529	+0.375
4476	0.391
4405	0.334
4384	0.327

For

$\lambda = 4482,\ d_1 = +0.366$

$d_2 = -0.982$

Displacem't = −0.616

July 11

λ	d_1
4529	−0.221
4405	0.271
4384	0.285

For

$\lambda = 4482,\ d_1 = -0.243$

$d_2 = -0.011$

Displacem't = −0.254

July 22

λ	d_1
4529	−0.226
4415	0.267
4405	0.261
4384	0.260

For

$\lambda = 4482,\ d_1 = -0.243$

$d_2 = -0.425$

Displacem't = −0.668

July 12

λ	d_1
4529	+0.391
4405	+0.330
4384	+0.299

For

$\lambda = 4482,\ d_1 = +0.364$

$d_2 = -0.266$

Displacem't = +0.098

July 13

λ	d_1
4529	+0.801
4405	0.739
4384	0.731

For

$\lambda = 4482,\ d_1 = +0.777$

$d_2 = -0.390$

Displacem't = +0.387

July 15

λ	d_1
4529	+0.049
4415	0.002
4405	0.005
4384	0.002

For

$\lambda = 4482,\ d_1 = +0.021$

$d_2 = +0.688$

Displacem't = +0.709

July 26

λ	d_1
4529	+0.255
4495	0.199
4476	0.227
4467	0.228
4405	0.220

For

$\lambda = 4482,\ d_1 = +0.228$

$d_2 = +0.162$

Displacem't = +0.390

July 31		July 24		July 27	
λ	d_1	λ	d_1	λ	d_1
4529	−0.052	4529	−0.050	4529	+0.007
4415	0.076	4415	0.081	4476	+0.003
4405	0.080	4405	0.078	4467	+0.021
4384	0.091	4384	0.079	4405	−0.019
For		For		4384	−0.021
$\lambda = 4482$, $d_1 =$	−0.062	$\lambda = 4482$, $d_1 =$	−0.064	For	
$d_2 =$	+0.056	$d_2 =$	−0.189	$\lambda = 4482$, $d_1 =$	+0.006
				$d_2 =$	+0.625
Displacem't =	−0.006	Displacem't =	−0.253		
				Displacem't =	+0.631

August 2		July 25		July 30	
λ	d_1	λ	d_1	λ	d_1
4529	+0.185	4529	−0.109	4529	+0.004
4495	0.145	4415	0.147	4415	−0.004
4476	0.162	4405	0.160	4405	+0.015
4415	0.151	4384	0.164	4384	−0.002
4405	0.144	For		For	
4384	0.129	$\lambda = 4482$, $d_1 =$	−0.126	$\lambda = 4482$, $d_1 =$	+0.003
For		$d_2 =$	+0.159	$d_2 =$	+0.314
$\lambda = 4482$, $d_1 =$	+0.171				
$d_2 =$	−0.737	Displacem't =	+0.033	Displacem't =	+0.317
Displacem't =	−0.566				

To find the radial velocities in geographical miles I have calculated the coefficient K from the measures made on several solar spectrograms. As argument, instead of the temperature, I have always employed the length of the interval λ 4405 − 4308 expressed in revolutions of the screw. In this way the following table has been obtained:

Argument	K	log. K	Argument	K	log. K
30.02	34.45	1.5372	30.09	34.40	1.5366
.03	.44	.5371	.10	.30	.5364
.04	.43	.5370	.11	.39	.5364
.05	.43	.5370	.12	.38	.5363
.06	.42	.5369	.13	.37	.5362
.07	.41	.5367	.14	.36	.5361
.08	.41	.5367	.15	.36	.5361

The following table contains the results of the measures and computations. The last column contains the intervals of time between the principal minimum and the moment of observation.

No.	Pulkowa mean time	Displacement	Radial velocity (geog. miles)	Radial velocity (kilom.)	Reduction to Sun (geog. miles)	Reduction to Sun (kilom.)	Velocity relative to Sun (geog. miles)	Velocity relative to Sun (kilom.)	Interval from minimum
1..	1897, June 20 $11^h.5$	+0.511	+17.60	+130.6	+0.67	+5.0	+18.27	+135.6	11^d 1^h
2..	22 12 .0	−0.093	− 3.20	− 23.8	+0.60	+4.5	− 2.60	− 19.3	0 3
3..	23 12 .4	−0.325	−11.19	− 83.0	+0.57	+4.2	−10.62	− 78.8	1 3
4..	24 11 .8	−0.567	−19.54	−145.0	+0.53	+3.9	−19.01	−141.1	2 3
5..	24 12 .5	−0.649	−22.33	−165.7	+0.53	+3.9	−21.80	−161.8	2 4
6..	28 11 .6	−0.335	−11.53	− 85.6	+0.39	+2.9	−11.14	− 82.7	6 3
7..	30 11 .1	+0.402	+13.85	+102.8	+0.31	+2.3	+14.16	+105.1	8 2
8..	July 2 11 .9	+0.614	+21.14	+156.9	+0.24	+1.8	+21.38	+158.7	10 3
9..	8 11 .9	−0.751	−25.86	−191.9	+0.02	+0.1	−25.84	−191.8	3 5
10..	8 12 .5	−0.701	−24.11	−178.9	+0.02	+0.1	−24.09	−178.8	3 6
11..	9 11 .4	−0.745	−25.66	−190.4	−0.02	−0.1	25.68	−190.5	4 4
12..	10 11 .1	−0.616	−21.21	−157.4	−0.06	−0.4	−21.27	−157.8	5 4
13..	11 11 .0	−0.254	− 8.74	− 64.9	−0.09	−0 7	− 8.83	− 65.6	6 4
14..	12 11 .5	+0.098	+ 3.37	+ 25.0	−0.13	−1.0	+ 3.24	+ 24.0	7 5
15..	13 11 .4	+0.387	+13.32	+ 98.9	−0.17	−1.3	+13.15	+ 97.6	8 4
16..	15 11 .4	+0.709	+24.40	+181.1	−0.25	−1.9	+24.15	+179.2	10 4
17..	17 11 .2	+0.310	+10.66	+ 79.1	−0.32	−2.4	+10.34	+ 76.7	12 4
18..	21 11 .2	−0.787	−27.05	−200.7	−0.47	−3.5	−27.52	−204.2	3 6
19..	22 11 .2	−0.668	−22.97	−170.4	−0.51	−3.8	−23.48	−174.2	4 6
20..	24 10 .3	−0.253	− 8.70	− 64.6	−0.58	−4.3	− 9.28	− 68.9	6 5
21..	25 10 .2	+0.033	+ 1.14	+ 8.5	−0.61	−4.5	+ 0.53	+ 4.0	7 5
22..	26 10 .0	+0.390	+13.42	+ 99.6	−0.65	−4.8	+12.77	+ 94.8	8 5
23..	27 10 .2	+0.631	+21.71	+161.1	−0.68	−5.0	+21.03	+156.1	9 5
24..	30 10 .1	+0.317	+10.90	+ 80.9	−0.79	−5.9	+10.11	+ 75.0	12 5
25..	31 10 .2	−0.006	− 0.21	− 1.6	−0.82	−6.1	− 1.03	− 7.7	0 7
26..	August 2 9 .7	−0.566	−19.47	−144.5	−0.89	−6.6	−20.36	−151.1	2 7

The argument measured on each spectrogram of the star is:

June 20	30.04	July 9	30.02	July 22	30.11
22	.11	10	.05	24	.11
23	.05	11	.07	25	.05
24	.07	12	.07	26	.08
28	.04	13	.07	27	.09
30	.03	15	.07	30	.11
July 2	.06	17	.10	31	.10
8	.05	21	.10	August 2	.09

Taking 12.908 days as the period of light change, let us draw a curve of radial velocities, using the values given in the preceding table (Fig. 1). According to the *Annuaire du Bureau des Longitudes* the principal minimum occurred:

1897, June 9, 17^h Pulkowa Mean Time; June 22, 7^h; July 5, 7^h; July 18, 5^h; July 31, 3^h.

II Minimum: June 28, 19^h; July 11, 17^h; July 24, 15^h.

I Maximum: June 25, 14^h; July 8, 12^h; July 21, 10^h; Aug. 3, 8^h.

II Maximum July 2, 0^h; July 14, 22^h; July 27, 20^h.

The differences between the curve of the observed velocities can be explained in part by the remarks appended to the measures: July 9, "The line is diffuse and badly defined;" July 15, "Faint;" July 8, "The artificial line at $\lambda 4529$ is hardly visible."

By means of the curve which satisfies the necessary conditions, we find the following elements:

Proper motion of the system $= -2.00$ geog. miles $= -14.8^{km}$

$$Z_1 = +450 \qquad Z_2 + Z_1 = -68$$
$$Z_2 = -518 \qquad Z_2 - Z_1 = -968$$

$A = 24.60$ geog. miles $= 182.5^{km}$. $A + B = 48.8$ geog. miles $= 362.1^{km}$

$$2\sqrt{A \times B} = 48.80$$

$B = 24.20$ geog. miles $= 179.6^{km}$. $A - B = +0.4$ geog. miles $= 3.0^{km}$

$\log.\tan.\ u_1 = 2.0863n$

$u_1 = 90^\circ.4 =$ point at which radial velocity $= 0$

$\log e \cos\omega = 8.8466$

$\log e \sin\omega = 7.9109$

$\tan\omega = 0.9357$

$\omega = 83^\circ.4 =$ long. of periastron.

$$e = 0.07 \qquad \left(\frac{dz}{dt}\right) = +\ 3.01 \text{ geog. miles} = 22.3^{km}$$

The time of periastron passage $T = +\ 0^d\ 4^h$, or $+\ 7^d\ 1^h =$ the time of apastron passage.

Finally, $a \sin i = 4318000$ geog. miles $= 32^{km} \times 10^6$, and supposing $i = 90°$, $a = 4318000$ geog. miles $= 32^{km} \times 10^6$

The curve of radial velocities shows that the changes of brightness may be sufficiently well explained by an eclipse; for the times of radial velocity $= 0$ are very close to the times of minima I and II.

It may be remembered that I have found that the bright F line also gives periodic radial velocities, and that the semi-axis of the orbit of the star whose spectrum contains this line $=$ 2130000 geographical miles ($15.8 \times 10^{6\,km}$). But although the velocities given by the measures of the dark line at λ 4482 are negative after the principal minimum, those given by the bright F line are positive after the minimum. Thus the dark line at λ 4482 belongs to one star, and the bright F line to another, and during the principal minimum it is the star giving the line at λ 4482 which is eclipsed; during the II minimum the star giving the bright F line is eclipsed.[1]

These results are in accordance with the conclusions of Dr. M. Myers (*Inaugural Dissertation*), and M. Tikhoff (*Mem. Spettr. Ital.*). I hope soon to attempt a further analysis of the bright F line.

[1] In my article "Le spectre de l'étoile variable β Lyrae," page 431, we read: "We thus suppose that the star at the time of minimum brightness is at one of its nodes, or rather that one of the stars of the system is at the node. This hypothesis is based on the fact that the continuous spectrum becomes very faint at the time of the principal minimum, while the bright F line and also the line at λ 5014 do not sensibly diminish in intensity; thus we observe about this time a partial eclipse of one of the stars"—of that which does not give the bright F line.

ON THE CONSTITUTION OF THE RED SPECTRUM OF ARGON.

By J. R. RYDBERG.

1. IMMEDIATELY after the discovery of argon attempts were made by means of spectrum analysis to determine the nature of the new gas. But the curious detection by Crookes[1] of the double spectrum of argon, the red and the blue, instead of clearing up the question, only made it more complicated, by giving rise to the hypothesis that argon was a mixture of two different elements, without affording the means of deciding as to the justness of such a supposition. In order to ascertain whether relations were to be found between the two spectra, I submitted the determinations of Crookes to a careful examination, but with no other result than the conviction that the precision of the measurements did not suffice for the present purpose. A trial with the first wave-length determinations of Eder and Valenta[2] succeeded better, numerous constant differences of wave-numbers being found, and I was about to publish the results obtained, when the first researches of the argon spectra by Kayser,[3] who stated his intention to make similar inquiries, decided me to defer for a time the publication of the relations found. If Professor Kayser were to succeed in arranging the spectra, it would be only just that the satisfaction of drawing the conclusions should follow such a troublesome investigation; if not, the new determinations would be very welcome to strengthen and to complete my former results. In his second publication[4] Kayser has given with a very high degree of precision the wave-lengths of the two spectra of argon. He mentions that he has done a great deal of work in searching for series

[1] *Z. f. phys. Chem.*, **16**, 369–379, 1895.

[2] "Über das rothe Spectrum des Argons." *Akad. Anzeig.*, No. XXI; *Sitz. d. math. naturw. Classe*, **24**, October 1895.

[3] *Chem. News*, **72**, 99, 1895.

[4] This JOURNAL, **4**, 1–17, 1896.

of related lines, but without being successful in this direction. However, as the three pairs of lines given by Kayser as triplets of the red spectrum enter into the grouping of lines which I had already found, it was to be expected that a continuation of the researches would shortly follow. But nothing more has been published, and, in the meantime, a new detailed investigation by Eder and Valenta[1] has further enriched the material for studies of the spectra. Therefore I now deem it proper to publish my observations on the constitution of the red spectrum of argon, deferring for the present the examination of the blue spectrum.

2. According to the statements of Crookes, Kayser, and Eder and Valenta, both spectra of argon can be obtained in Geissler tubes under various conditions, but in general the variations in the intensities of the different spectral lines seem to depend on the quantity of energy which a molecule of the gas receives from the current in unit time, the time, of course, being counted only when a discharge is passing. Every spectral line has a maximum of intensity, corresponding to a certain value of the energy of vibration of the molecule, but varying for different vibrations. The lines which are ascribed to the red spectrum attain their maxima at lower temperatures than those forming the blue spectrum, and disappear gradually when the temperature rises, the lines of the blue spectrum growing stronger. In this way it is possible to obtain at relatively low temperatures a "red spectrum," and at considerably higher temperatures a "blue spectrum," which have no lines in common. In general, however, only "mixed spectra" are produced; but if we adhere to the firm conviction that we really have to do with two different spectra, the difficulty of common lines can be easily overcome by always ascribing the lines which grow weaker at higher temperatures to the red spectrum, and those whose intensity increases under these conditions to the blue spectrum. In this way, I think, both the pure spectra of argon may be obtained.

In order to form a better judgment regarding the agreement

[1] *Denkschr. d. k. Akad. d. W. Wien*, **64**, 1896.

of these views with the details of the various researches we will seek an approximate expression for the energy transmitted by the current to the molecules of the gas. Let V_1 and V_2 be the potentials at the electrodes, which we assume, for greater simplicity, to be directly introduced at the ends of the cylindrical capillary tube ; Q the quantity of electricity discharged in the time t (a fraction of the time of the shortest discharge used); l the length and a the sectional area of the tube ; n the number of molecules in unit volume at unit pressure and at 0°; and P the pressure of the included gas when at 0°. Then the whole quantity of energy given off by a discharge in unit time is $\frac{Q(V_1 - V_2)}{t}$, and the number of molecules in the tube, $P \cdot n \cdot a \cdot l$. Therefore the quantity of energy transmitted to every molecule in unit time is, in a first approximation,

$$\frac{Q\,(V_1 - V_2)}{t \cdot l \cdot n \cdot P \cdot a}.$$

This expresssion increases with the strength of the current $\frac{Q}{t}$ and with the force $\frac{V_1 - V_2}{l}$; it also increases when the gas is rarefied or when the sectional area of the capillary tube is reduced. According to the experiments of the authors quoted, all these methods of augmenting the energy of the molecules also suffice to transform the red spectrum of argon first into a mixed spectrum and then at last into the pure blue spectrum. Here we have the introduction of a condenser, the strengthening of the current, the change of the pressure, and, finally, the observation of Eder and Valenta that, when the capillary gives the blue spectrum, a mixed spectrum is shown by the light in the wider portions of the tube at both poles. The only observation that cannot be explained in this simple way is the reverse phenomenon, when the red spectrum in the capillary tube corresponds to a mixed spectrum in the wider parts. I think it would be of interest to examine the spectra produced in a tube having a capillary of varying width.

3. I have limited my researches to that part of the red spectrum of argon (4702–2967) which has been determined by Kayser with the greatest precision. Moreover, I have admitted several lines observed by Eder and Valenta which find a place in the discovered grouping of lines, but were not seen by Kayser. It has not been possible to take the less refrangible portion of the red spectrum into account, the greater part of the lines of Eder and Valenta in this region belonging most likely to the blue spectrum, as they give no constant differences, such as those which characterize the red spectrum; while the values of Kayser, which really seem to correspond to the rest of the red spectrum, obviously lack the precision necessary for the present investigation. From the eighty-one lines given by Kayser in this region of the spectrum, at least one-half can be inserted in the same grouping of lines with the others, but as there can be given no sufficient proof of their real correspondence without new and more exact measurements, I have passed over these lines altogether.

The wave-lengths after Kayser (K.) and Eder and Valenta (E. V.), and the computed wave-numbers (number of waves in 1^{cm}) of the lines examined are given in Table I, together with their intensities according to both the series of observations quoted. The last column contains provisional designations for the lines which have been arranged and entered in Table II, and remarks concerning several of the other lines ascribed to the red spectrum of argon.

In examining the last column of the table we see that of the ninety-five lines given by Kayser between 4702 and 2967 not less than fifty-nine are inserted in Table II, among them the two lines 4198.162 and 4191.841, whose considerable deviations from the corresponding values of Eder and Valenta must attract special attention. On closer inspection it appears that these values have been inserted by error instead of 4198.436 and 4191.162, the values given as examples by Kayser on page 8. The line 3564.423 occurs twice, and seems to agree equally well in both places. Possibly the line is double. Of the remaining thirty-six lines

TABLE I.

RED SPECTRUM OF ARGON FROM λ 4702–λ 2967 ACCORDING TO KAYSER AND EDER AND VALENTA.

Obs.	Intensity		Wave-length	Wave-number	Designations and remarks
	K.	E. V.			
K.	4	5	4702.504	21265.27	A_1
"	3	8	4628.623	21604.70	A_2
"	3	8	4596.205	21757.08	A_3
E. V.	—	5	4589.40	21789.34	A_4 From the red spectrum of E. V. (1)
K.	3	6	4522.389	22112.21	B_1
"	5	10	4510.851	22168.77	A_5
E. V.	—	1	4424.09	22603.52	B_3 From the red spectrum of E. V. (2)
K.	1	4	4363.970	22914.91	C_1
"	4	10	4345.322	23013.25	A_6
"	4	8	4335.491	23065.44	A_7
"	6	6	4333.714	23074.90	A_8
"	1	—	4304.033	23234.02	Not seen by E. and V. "Ghost" (?)
"	6	10	4300.249	23254.47	C_2
"	6	10	4272.304	23406.57	C_3
"	5	10	4266.425	23438.83	C_4
"	7	10	4259.491	23476.98	A_9
"	3	6	4251.329	23522.06	D_1
"	1	—	4205.007	23781.17	Not seen by E. and V. "Ghost"
"	9	10	4200.799	23805.00	
"	5	10	4198.436	23818.40	C_5 Corrected values. See K., p. 8 4198.162
"	5	10	4191.162	23859.73	B_6 In the table Kayser has by error 4191.841
"	5	5	4190.841	23861.56	D_2
"	5	9	4182.002	23911.99	B_7
E. V.	—	2	4180.38	23921.27	B_8 From the white spectrum of E. V. (2)
K.	5	9	4164.309	24013.59	D_3
"	1	—	4162.906	24021.68	Not seen by E. and V. "Ghost"
"	9	10	4158.722	24045.85	D_4
"	2	—	4154.657	24069.38	Not seen by E. and V. "Ghost"
"	2	5	4054.663	24662.96	C_6
"	2	—	4046.620	24711.98	Probably Hg[S_3, 2]=4046.78 (K. R.)
"	2	6	4046.027	24715.60	C_7
"	7	10	4044.565	24724.54	C_8
E. V.	—	3	4033.11	24794.76	A_{10} From the red spectrum of E. V. (2)
"	—	2	3979.81	25126.83	C_9 From the red spectrum of E. V. (1)
K.	6	10	3949.107	25322.18	D_7
"	4	5	3947.645	25331.56	D_8
"	1	4	3900.065	25640.60	B_{10}
"	2	5	3894.795	25675.29	A_{12}
"	1	2	3866.353	25864.17	A_{14}
"	1	3	3850.693	25969.35	Stronger in the blue spectrum of E. V.
"	4	6	3834.768	26077.20	A_{16}
"	1	—	3801.049	26308.53	Not seen by E. and V.
"	2	4	3781.461	26444.81	C_{10}
"	1	2	3775.476	26486.73	C_{11}
"	3	4	3770.440	26522.10	B_{12}
"	1	1	3743.808	26710.77	B_{14}
"	1	1	3738.030	26752.06	Stronger in the blue spectrum of E. V.
"	1	2	3696.587	27051.98	D_{10}
"	2	4	3691.001	27092.92	D_{11}
"	1	2	3675.353	27208.27	A_{17}
"	2	4	3670.783	27242.14	A_{19}

TABLE I—*Continued.*

Obs.	Intensity K.	Intensity E. V.	Wave-length	Wave-number	Designations and remarks
K.	1	—	3663.392	27297.11	Probably Hg $[D_{13}, 2]$=3663.25 (K. R.)
"	2	3	3659.632	27325.15	C_{12}
"	1	—	3654.962	27360.07	Probably Hg $[D_{12}, 2]$=3654.94 (K. R.)
"	2	—	3650.258	27395.32	Probably Hg $[D_{11}, 2]$=3650.31 (K. R.)
"	2	3	3643.227	27448.19	C_{13}
"	3	6	3634.586	27513.45	C_{14}
"	3	6	3632.766	27527.23	C_{15}
"	5	6	3606.677	27726.35	C_{16}
"	1	2	3599.822	27779.15	A_{20}
"	2	3	3572.416	27992.26	A_{22}
"	4	4	3567.789	28028.56	
"	3	4	3564.423	28055.03	B_{17} and D_{13}
"	3	4	3563.362	28063.39	B_{18}
E. V.	—	5	3560.15	28088.70	B_{19} From the white spectrum of E. V. (2)
K.	1	3	3559.601	28093.04	Stronger in the blue spectrum of E. V.
"	2	3	3556.135	28120.42	D_{14}
"	5	4	3554.435	28133.87	D_{15}
"	1	—	3545.947	28201.21	A_{23} Not seen by E. and V.
"	1	1	3514.513	28453.44	Stronger in the blue spectrum of E. V.
"	1	—	3509.934	28490.56	Only seen in the blue spectrum by E. V.
"	2	2	3506.650	28517.25	
"	1	3	3493.435	28625.12	B_{20}
"	1	1	3476.894	28761.30	Stronger in the blue spectrum of E. V.
"	3	4	3461.192	28891.78	C_{19}
"	1	1	3455.076	28942.92	
"	1	1	3442.640	29047.48	B_{23}
"	1	2	3406.287	29357.48	
"	1	—	3398.016	29428 94	C_{20} Not seen by E. and V.
"	3	4	3393.848	29465.08	D_{17}
"	2	3	3392.885	29473.44	D_{18}
"	1	1	3389.955	29498.92	D_{19}
"	1	—	3388.464	29511.90	Only seen in the blue spect'm by E. V.
"	1	2	3387.698	29518.57	C_{21}
"	1	2	3381.573	29572.04	
"	2	3	3373.586	29642.05	C_{22}
"	1	—	3360.146	29760.61	Not seen by E. and V.
"	1	—	3341.637	29925.45	Probably Hg $[S_1, 3]$=3341.70 (K. R.)
"	2	2	3325.626	30069.53	
"	3	2	3319.459	30125.39	D_{21}
"	1	—	3303.08	30274.77	Probably Na $[P_2, 2]$=3303.07 (K. R.)
"	3	—	3302.50	30280.09	Probably Na $[P_1, 2]$=3302.47 (K. R.)
"	2	—	3295.44	30344.96	Not seen by E. and V.
"	1	—	3244.51	30820.92	Not seen by E. and V.
"	1	—	3175.11	31494.97	Not seen by E. and V.
"	2	—	3131.90	31929.50	Probably Hg $[D_{23}, 2]$=3131.94(K. R.)
"	4	—	3125.70	31992.83	Probably Hg $[D_{22}, 2]$=3125.78(K R.)
"	4	4	3021.52	33095.93	Probably Hg $[D_{11}, 3]$= 3021.64(K. R.)
"	1	—	2972.60	33640.58	Not seen by E. and V.
"	2	—	2968.39	33688.30	Not seen by E. and V.
"	5	5	2967.35	33700.10	Probably Hg $[D_{33}, 2]$=2967.37(K. R.)

nine undoubtedly belong to the spectrum of mercury and two to sodium. Only two of these lines are given by Eder and Valenta. To the blue spectrum we can ascribe with great probability seven lines, which were seen by Eder and Valenta in this spectrum only, or at least appeared there in their greatest intensity. Further four lines are met with not observed by Eder and Valenta, of which three at all events may be ascribed to "ghosts" of adjacent strong lines. Determinations in the spectra of other orders ought to show the same absolute distances between the "ghosts" and the principal lines, but with wave-lengths proportionally changed. In the blue spectrum it appears that Kayser has inserted about forty of these "ghosts" as real lines. They follow the rule $\Delta\lambda = \pm K\frac{\lambda}{N}$, $\Delta\lambda$ being the difference in wave-length from the principal line of wave-length λ, N the order of spectrum, and K a constant. In the present case $K = 0.001\,N$. Kayser has seven lines more of intensities 1 and 2, not seen by Eder and Valenta, so that of the ninety-five lines there remain but seven, which have been observed in both the investigations referred to without being inserted in Table II or otherwise accounted for. Of these the line 4200.799 is the most remarkable as probably the strongest line in the red spectrum, its intensity, according to Kayser, being 9, while Eder and Valenta call it 10. If this line, as is asserted by Eder and Valenta, has nothing to do with the spectrum of nitrogen, it will possibly form the first component of a term of a compound double line, as is often the case with the strongest lines in the line spectra hitherto examined. Of the rest only the line 3567.789 has the intensity 4; the others are weak lines of intensities 1 or 2. The lines cited from Eder and Valenta are obtained in such a way that the wave-numbers for the gaps in the grouping of lines in Table II have been computed and the corresponding wave lengths sought for in the blue spectrum of Kayser and in the tables of Eder and Valenta. In the first mentioned spectrum none of the missing lines have been found, but four lines from the red spectrum of Eder and Valenta and two lines from the white

TABLE II.

LINES OF CONSTANT DIFFERENCES IN THE RED SPECTRUM OF ARGON.

No.	A	Diff. 846.47	B = A + 846.47	Diff. 803.21	C = A + 1649.68	Diff. 607.03	D = A + 2256.71
1	4 (5) 21265.27	846.94	3 (6) 22112.21	1649.64	1 (4) 22914.91	2256.79	3 (6) 23522.06
2	3 (8) 21604.70	......	....	1649.77	6 (10) 23254.47	2256.86	5 (5) 23861.56
3	3 (8) 21757.08	846.44	((1) 22603.52)	1649.49	6 (10) 23406.57	2256.51	5 (9) 24013.59
4	((5) 21789.34)	......	....	1649.49	5 (10) 23438.83	2256.51	9 (10) 24045.85
5	5 (10) 22168.77	......	....	1649.63	5 (10) 23818.40	....	....
6	4 (10) 23013.25	846.48	5 (10) 23859.73	1649.71	2 (5) 24662.96	....	....
7	4 (8) 23065.44	846.55	5 (9) 23911.99	1650.16	2 (6) 24715.60	2256.74	6 (10) 25322.18
8	6 (6) 23074.90	846.37	((2) 23921.27)	1649.64	7 (10) 24724.54	2256.66	4 (5) 25331.56
9	7 (10) 23476.98	......	....	1649.85	((2) 25126.83)	....	....
10	((3) 24794.76)	845.84	1 (4) 25640.60	1650.05	2 (4) 26444.81	2257.22	1 (2) 27051.98
11	....	......	....	....	1 (2) 26486.73	(606.19)	2 (4) 27092.92
12	2 (5) 25675.29	846.81	3 (4) 26522.10	1649.86	2 (3) 27325.15	....	....
13	....	......	....	....	2 (3) 27448.19	(606.84)	3 (4) 28055.03
14	1 (2) 25864.17	846.60	1 (1) 26710.77	1649.28	3 (6) 27513.45	2256.25	2 (3) 28120.42
15	....	......	....	....	3 (6) 27527.23	(606.64)	5 (4) 28133.87
16	4 (6) 26077.20	......	....	1649.15	5 (6) 27726.35	....	....
17	1 (2) 27208.27	846.76	3 (4) 28055.03	....	....	2256.81	(3) 4 29465.08
18	....	......	3 (4) 28063.39	....	....	(1410.05)	(2) 3 29473.44
19	2 (4) 27242.14	846.56	((5) 28088.70)	1649.64	3 (4) 28891.78	2256.78	(1) 1 29498.92
20	1 (2) 27779.15	845.97	1 (3) 28625.12	1649.79	1 (-) 29428.94	....	....
21	....	......	....	....	1 (2) 29518.57	(606.82)	3 (2) 30125.39
22	2 (3) 27992.26	... .	....	1649.79	2 (3) 29642.05	....	....
23	1 (-) 28201.21	846.27	1 (1) 29047.48	....	....	....	....

spectrum have been included in Table II, where they are inclosed in brackets. The accordance of the last two lines is perhaps only accidental.

4. After thus accounting for the lines examined, we pass to Table II, which contains the wave-numbers of the above-mentioned lines arranged in such a way that lines belonging to corresponding columns (A–D) in all the rows (1–23) show the same differences. These differences are given to the left of each of the succeeding columns as referred to the corresponding line of the first; if such a line is wanting they refer to one of the following columns. The figures given before the wave-numbers indicate the intensity; for example, 4 (5) signifies that the intensity of the line is 4 according to Kayser and 5 according to Eder and Valenta.

The great number of closely accordant differences speaks well for the given arrangement of the lines as well as for the precision of the determinations. Of course it is not impossible that a few of the lines fit into their places only by chance, but in general there can be no doubt as to the reality of the connections shown in the table.

The wave-numbers of the lines in the succeeding columns are given through the relations

$$B = A + 846.47,$$
$$C = A + 1649.68,$$
$$D = A + 2256.71.$$

The other differences which occur are

$$C - B = 803.21,$$
$$D - B = 1410.24,$$
$$D - C = 607.03.$$

In seven rows four lines are known, in six others the number of lines is three, and in the remaining ten we have only two. The B-column seems to possess the least mean intensity as well as the least number of lines, but no simple regularity as to the intensity has yet been found, the maxima and minima of the rows occurring in any column. According to analogy from the com-

pound triplets in the simpler line-spectra, we may expect that some of the gaps are real ones, while others are more likely to depend upon the feeble intensity of the lines. I have not succeeded in finding anything like the well-known series of the line-spectra already arranged, and I am inclined to believe that we have to do with a new class, or, perhaps better, a new subdivision of spectra which ought to have close relations to the others, but, no doubt, are much more complicated. These spectra seem to occur in all elements at higher temperatures than those hitherto employed in such work, as, for instance, generally in spark-spectra, but also in the arc-spectra of many elements.

Certain regularities in the red spectrum of argon, whether real or accidental I would not venture to say, ought not to be passed without mention. The rows 3 and 5 give approximately the same difference as 7 and 9, viz., 411.57, and, moreover, the rows 3 and 7 are followed by adjacent rows 4 and 8, forming in this way two groups of lines of analogous constitution. The double rows 10–11, 12–13, 14–15, and 20–21, are suggestively similar, and recall the compound triplets of several elements, a row A, B, C, D, or A, B, C being accompanied by an adjacent short row, C, D.

5. But whatever opinion we may entertain regarding these regularities and the general constitution of the class of spectra in question, it results as an indisputable consequence of the foregoing investigation, that *the red spectrum of argon belongs to one single element.* Moreover, there seems to be no reason to doubt that the blue spectrum belongs to the same element, but corresponds to a higher temperature. In order to give a definite proof it will, of course, be necessary to arrange also the blue and the white spectra of argon, and then to demonstrate the connection between all the spectra of the gas. As to the supposed displacement of a great number of the lines of the white spectrum toward the red end of the spectrum, nothing seems to indicate that we have to do with a *continuous* displacement, but rather with the appearance of new lines on the red side of

those of the other spectra, with which they ought to be closely related. In such a case it seems most probable that the interesting observation of Eder and Valenta depends on a change in the relative intensity of two sets of connected lines.

LUND, August 15, 1897.

SPECTRA OF BRIGHT SOUTHERN STARS.

By Edward C. Pickering.

A detailed description of the spectra of the stars brighter than the fifth magnitude, and north of declination $-30°$, by Miss A. C. Maury, and forming part of the Henry Draper Memorial, will be found in the *Annals of the Harvard College Observatory*, Vol. XXVIII, Part I. A similar discussion of the bright stars south of declination $-30°$ is now being made by Miss A. J. Cannon, and will be published in Part II of the same volume. Meanwhile, in order to furnish astronomers with a general classification of the spectra of the southern stars the annexed table has been prepared by Miss Cannon. It contains all stars south of declination $-30°$, whose photometric magnitude is 3.50 or brighter. The designation of the star is given in the first column. The second column contains the number in the *Southern Meridian Photometry*, taken from Vol. XXXIV, Table XIII, of the Harvard Observatory *Annals*, where the identification with various other catalogues is also given. The approximate right ascension and declination for 1900 and the photometric magnitude are given in the next three columns. The seventh column contains the class of spectrum. The classification here given is that employed in the *Draper Catalogue*, the letters A, G, M, N, and O indicating stars of the first, second, third, fourth, and fifth types respectively. The letter B denotes a star of the first type, in which the Orion lines are present and nearly as intense as the hydrogen lines. The letter F denotes a star of the first type in which the hydrogen lines are rather faint and the line K is strong. The letter K denotes a spectrum intermediate between the second and third types as indicated by sudden changes in intensity. The types B, A, F, G, K, and M, therefore, indicate divisions in a continuous sequence, in which there are many subdivisions. Intermediate spectra are indicated by two letters and a number giving the position esti-

BRIGHT SOUTHERN STARS.

	S. M. P.	R. A. 1900	S. Dec. 1900	Phot. Mag.	Class
β Hydri	57	0^h $20^m.5$	77° 49′	2.89	G
α Phoenicis	59	21 .3	42 51	2.45	K
β Phoenicis	187	1 1 .6	47 15	3.39	G 8 K
γ Phoenicis	257	24 .0	43 50	3.32	K 5 M
α Eridani	290	34 .0	57 44	0.51	B 3 A
α Hydri	356	55 .6	62 4	2.96	A 5 F
θ Eridani	584	2 54 .5	40 42	3.13	A 2 F
γ Hydri	779	3 48 .8	74 33	3.12	M
α Reticuli	868	4 13 .1	62 43	3.35	G 5 K
α Columbae	1217	5 36 .0	34 8	2.74	Q
β Columbae	1284	47 .5	35 49	3.06	K
ζ Canis Majoris	1444	6 16 .5	30 2	3.25	B 3 A
α Carinae	1480	21 .8	52 39	−0.96	F
ν Puppis	1569	34 .7	43 6	3.23	B 8 A
α Pictoris	1650	47 .2	61 50	3.29	A 4 F
τ Puppis	1653	47 .4	50 30	2.76	K
π Puppis	1845	7 13 .6	36 55	2.49	K 5 M
σ Puppis	1951	26 .1	43 6	2.99	K 5 M
c Puppis	2075	41 .7	37 44	3.40	K 5 M
ζ Puppis	2248	8 0 .1	39 43	2.33	Q
γ Velorum	2305	6 .5	47 2	1.91	O
ε Carinae	2441	20 .4	59 11	1.74	Q
δ Velorum	2623	8 42 .0	54 20	2.00	A
λ Velorum	2777	9 4 .3	43 2	2.10	K 5 M
β Carinae	2844	12 .1	69 18	1.73	A
ι Carinae	2868	14 .4	58 51	2.24	F
κ Velorum	2911	19 .0	54 35	2.59	B 3 A
N Velorum	2996	28 .2	56 36	2.98	K 5 M
ν Carinae	3095	44 .6	64 37	2.99	A 5 F
q Carinae	3293	10 13 .7	60 50	3.42	K 5 M
θ Carinae	3476	39 .4	63 52	3.01	B 2 A
μ Velorum	3495	42 .5	48 54	2.81	G 5 K
λ Centauri	3883	11 31 .1	62 28	3.31	B 9 A
δ Centauri	4093	12 3 .2	50 10	2.81	Q
δ Crucis	4134	9 .8	58 11	3.08	B 3 A
α Crucis	4208	21 .1	62 32	1.02	B 2 A
γ Crucis	4242	25 .6	56 33	1.55	M
α Muscae	4270	31 .3	68 35	2.91	B 3 A
γ Centauri	4294	36 .0	48 24	2.36	A
β Muscae	4312	40 .1	67 33	3.26	B 3 A
β Crucis	4324	41 .8	59 8	1.49	B 2 A
ι Centauri	4507	13 15 .0	36 11	2.98	A 2 F
ε Centauri	4610	33 .6	52 58	2.58	B 2 A
μ Centauri	4676	13 43 .6	41 59	3.33	Q
ζ Centauri	4715	49 .3	46 47	2.81	B 2 A
β Centauri	4753	56 .7	59 53	0.83	B 2 A
θ Centauri	4775	14 0 .8	35 52	2.19	K
η Centauri	4941	29 .2	41 43	2.54	B 3 A
α^1 Centauri	4960	32 .8	60 25	0.50	G
α^2 Centauri	4961	32 .8	60 25	1.75	K 5 M
α Circini	4969	34 .4	64 33	3.37	A 5 F
α Lupi	4975	35 .2	46 57	2.46	B 2 A
β Lupi	5081	52 .0	42 44	2.74	B 2 A
κ Centauri	5085	52 .6	41 42	3.36	B 3 A
ζ Lupi	5163	15 5 .1	51 43	3.46	K

	S. M. P.	R. A. 1900	S. Dec. 1900	Phot. Mag.	Class
γ Triang. Aust.	5194	15^h $9^m.6$	68° 19′	3.00	A
δ Lupi	5220	14 .8	40 18	3.37	B 2 A
φ¹ Lupi	5230	15 .5	35 54	3.28	K 5 M
γ Lupi	5310	28 .5	40 50	2.96	B 3 A
β Triang. Aust.	5416	46 .4	63 7	3.09	F
α Triang. Aust.	5752	16^h 38 .0	68 51	1.89	K 2 M
ε Scorpii	5787	43 .7	34 7	2.29	K
μ¹ Scorpii	5794	45 .1	37 53	3.26	Q
ζ Aræ	5837	50 .4	55 50	3.02	K 5 M
η Scorpii	5930	17 5 .0	43 6	3.37	F 2 G
β Aræ	6020	17 17 .0	55 27	2.72	K 2 M
γ Aræ	6021	17 .0	56 17	3.42	B
ν Scorpii	6063	24 .0	37 13	2.84	B 2 A
α Aræ	6064	24 .1	49 47	2.86	Q
λ Scorpii	6082	26 .8	37 2	1.79	B 3 A
θ Scorpii	6104	30 .1	42 56	1.99	F
κ Scorpii	6154	35 .5	38 59	2.59	B 2 A
ι¹ Scorpii	6191	40 .5	40 6	3.10	F 5 G
G Scorpii	6204	43 .0	37 1	3.22	K 2 M
γ Sagittarii	6341	59 .4	30 25	3.02	K
η Sagittarii	6428	18 10 .9	36 48	2.96	M
ε Sagittarii	6471	17 .6	34 25	1.93	A
ζ Sagittarii	6686	56 .3	30 1	2.69	A 2 F
α Pavonis	7074	20 17 .7	57 3	2.05	B 3 A
α Indi	7126	30 .6	47 39	3.20	G 5 K
γ Gruis	7432	21 47 .9	37 50	3.20	B 8 A
α Gruis	7481	22 1 .9	47 27	1.92	B 8 A
α Tucanæ	7524	11 .6	60 46	2.90	K 2 M
β Gruis	7615	36 .7	47 24	2.09	M
α Piscis Aust.	7684	52 .1	30 9	1.27	A 3 F

mated in tenths of the interval between them; thus B 8 A denotes that the spectrum is between B and A and closely approaches A. The spectra of nearly all the stars in the table can be thus described. For the remainder the letter Q is inserted, and the peculiarities of the spectra are described in the following remarks.

REMARKS.

θ Eridani. The presence of the line K in the spectrum may be due to the fainter component.

γ Hydri. Spectrum like that of α Orionis.

α Columbæ. Spectrum B 8 A, except that $H\beta$ consists of a narrow bright line superposed on a broad dark band.

π Puppis. $H\beta$, $H\gamma$, and $H\delta$ are stronger than in α Tauri, the typical star of this class.

ζ Puppis. The spectrum of this star contains two bright bands at wavelengths 4633 and 4688, and a rhythmical series of lines falling between the well-known lines of hydrogen. See Harvard College Observatory *Circular* No. 16.

γ Velorum. This is the only bright star having a spectrum of the fifth type.

ϵ Carinæ. Composite type. Spectrum K, except that the line K is barely seen, and the hydrogen lines are strong. Perhaps the star is double, the fainter component having a spectrum of Class A.

δ Centauri. B 3 A, except that $H\beta$ consists of a strong bright line, $H\gamma$ of a bright line superposed on a broad dark band, and $H\delta$ of a narrow bright line superposed on a faint dark band. The presence of additional dark lines, as in other stars of this class, is well shown in this spectrum.

α Crucis. The lines are broad and ill defined, and the photographs do not show the spectra of the two components separately.

γ Crucis. Spectrum like that of α Orionis.

μ Centauri. Spectrum B 2 A. Like δ Centauri, except that $H\epsilon$ is also bright.

μ^1 Scorpii. Spectrum B 3 A. Spectroscopic binary. Period 1.4462 days.

α Aræ. Spectrum B 3 A, except that $H\beta$ is bright.

η Sagittarii. Spectrum like that of α Herculis.

β Gruis. Spectrum like that of α Herculis.

HARVARD COLLEGE OBSERVATORY,
Cambridge, Mass., October 8, 1897.

Minor Contributions and Notes.

THE DEDICATION OF THE YERKES OBSERVATORY.

The astronomical and astrophysical conferences held in connection with the dedication of the Yerkes Observatory were opened on Monday, October 18, at 2:30 P.M. in the Observatory library. Professor Hale announced that the afternoon session would be devoted to the fourth annual meeting of the Board of Editors of the Astrophysical Journal, at which the visiting men of science were invited to be present. Professor Pickering then took the chair. A communication from Professor Schuster,[1] regarding the mode of printing maps of spectra and tables of wave-lengths, was presented.

A general discussion followed the reading of this communication. The views of several members of the Board have already been printed in the Astrophysical Journal. They were considered at some length, and expressions of opinion were also invited from the astronomers and physicists who were attending the conferences held in connection with the dedication of the Observatory. Professor Runge thought that the mode of printing tables and the mode of printing maps were two distinct questions. The occurrence of line series in the spectra of the elements had an important bearing on the first question. In a table beginning with short wave-lengths the uncertain lines are at the top, which is an inconvenience. In the lower spectrum the lines are not doubtful. On the other hand, it is generally more convenient to have the numerical values in a table increase towards the bottom. A map can easily be turned end for end when it is necessary to compare it with another printed in the reverse direction. He did not think the subject an important one, was prepared to accept a decision in favor of either method, but thought harm was done by making a rule.

After some further discussion the following resolution was adopted: *Resolved:* That the Editorial Board adhere to the present practice of beginning tables with the short wave-lengths and of printing maps of the spectrum with the red end on the right, except in cases where a

[1]To be published in a subsequent number of this Journal.

wish to the contrary is expressed by the author of any contributed paper. It was also resolved that an announcement of this decision should be printed in the standing notice in each number of the JOURNAL.

Professor Schuster's suggestion regarding the position of the decimal point in wave-numbers (the number given being the number of wave-lengths in the centimeter) was generally approved. A discussion of a scale of intensity brought out the fact that all present were in favor of representing increasing intensities by increasing numbers. It was felt, however, that the time had not yet come to adopt a uniform scale of intensity, applicable to all classes of spectra.

The meeting annually held by the Board of Editors for the discussion of current investigations was merged in the general sessions of the conferences. The first paper presented was by Sir William and Lady Huggins, and dealt with some of the results obtained in their recent photographic studies of stellar spectra.[1] At the conclusion of the discussion of this paper the meeting adjourned.

The evening was partly cloudy, and it was consequently impossible to carry out the full programme of work with the forty-inch telescope, which included demonstrations by Professor Wadsworth of the application of interference methods to astronomical and astrophysical measurements, and observations of double stars by Professor Burnham. It was nevertheless found possible to show a few double stars after the adjournment of the second session of the conferences, at which Professor Pickering gave an account, illustrated by photographs and diagrams, of the variable star work of the Harvard Observatory.

The third session of the conferences was opened on Tuesday at 9:00 A.M., with Professor Runge in the chair. Professor Crew described his investigations of the flame of the rotating arc, which persists for an appreciable time after the current has been cut off. Photographs of the arc, taken under various conditions were exhibited. Professor Comstock followed with an account of recent work at the Washburn Observatory, including determinations of stellar parallax and investigations of the lunar atmosphere. He also exhibited a Steinheil double-image micrometer. At the conclusion of the discussion of this paper the meeting adjourned to the large dome, where Professor Hale and Mr. Ellerman exhibited various solar phenomena with the forty-inch telescope and solar spectroscope.

[1] See page 322. It is expected that the other papers presented at the conferences will be published in full or in part in subsequent numbers of this JOURNAL.

The afternoon session was called to order at 3:00 P.M., Professor Runge in the chair. Professor Hale gave an address on the aim of the Yerkes Observatory.[1] The meeting then adjourned to the laboratories and shops, where various demonstrations were made. In the optical laboratory Mr. Carl Lundin, of Alvan Clark & Sons, showed the method employed by his firm in testing telescope objectives. Professor Wadsworth exhibited in the adjoining spectroscopic laboratory an interferometer designed for the measurement of wave-lengths in infra-red metallic spectra. Professor Crew showed his rotating metallic arc in the physical laboratory, and exhibited its spectrum with a large plane grating spectroscope. The ten-foot focus concave grating was mounted in the adjoining room. In the northeast dome Professor Lord exhibited the stellar spectrograph of the Emerson McMillin Observatory, attached to the twelve-inch equatorial. Both the instrument and optical shops were in operation. In the former Mr. Lorenz showed a large heliostat and a mounting for a two-foot reflector in process of construction. Mr. Kathan exhibited the parts of a spectroheliograph which he is building for the forty-inch telescope. Mr. Mors showed a partly completed ruling-machine for optical gratings, and explained Rowland's method of grinding a perfect screw. He also exhibited a device for cutting a very long and perfect nut to exactly match a corresponding screw. In the optical shop Mr. Ritchey demonstrated the operation of a large grinding-machine carrying a five-foot glass disk for a speculum, and tested a two-foot mirror by Foucault's method. It had been expected that Dr. Humphreys would demonstrate with the concave grating the effect of pressure on wave-length. But unfortunately the pressure arc, which had been kindly loaned for the occasion by the Johns Hopkins University, did not reach the Observatory until after the conclusion of the conferences.

In the evening the sky was overcast, and a session of the conferences was substituted for the proposed observations with the forty-inch telescope. Professor Runge was in the chair. Professor Keeler exhibited with an electric lantern, kindly loaned for the occasion by the Colt Co., some photographs of the spectra of stars of the third type recently made at the Allegheny Observatory. Professor Lord followed with a talk on the stellar spectrographic work of the Emerson McMillin Observatory, with lantern illustrations. The next paper was by Pro-

[1] See page 309.

fessor Wadsworth, on the application of diffraction phenomena to astronomical and astrophysical measurements. At the close of the discussion it was announced that as the sky had partly cleared, Professor Barnard would exhibit nebulæ with the forty-inch telescope. Later in the evening the Board of Editors of the ASTROPHYSICAL JOURNAL held a special meeting.

On Wednesday the conference was called to order at 10:00 A.M., with Professor Rees in the chair. Professor Runge gave his reasons for supposing oxygen to be present in the Sun, and stated that Mr. Jewell had withdrawn his objections to the evidence previously offered. Dr. Humphreys exhibited a large number of original negatives taken at the Johns Hopkins University for the purpose of measuring the shifts of spectral lines due to pressure. Professor Doolittle gave an account of the latitude work of the Flower Observatory. The last paper of the session was by Professor Rees on the variation of latitude and the reduction of the Rutherfurd photographs. All the papers were fully discussed.

The afternoon session was called to order at 3:00 P.M. by Professor Van Vleck. Father Hedrick spoke on the photochronograph, and exhibited the instrument used at the Georgetown College Observatory, together with photographs obtained with it. Professor Pritchett spoke on personal equation in longitude determinations, giving the results of his own extensive observations. Professor Poor described a new form of mirror for reflecting telescopes, and sketched a convenient style of mounting for it. Professor Newcomb discussed the problem of determining the distribution of the stars, and dwelt upon the great importance of measuring with the spectroscope the motion of the solar system in space. Father Hagen described his forthcoming atlas of variable stars, specimen sheets of which were exhibited. Professor Myers concluded the afternoon session with a paper on the system of β Lyrae. As usual, the papers were fully discussed.

As the evening was cloudy the sessions were continued, with Professor Van Vleck in the chair. Mr. Yerkes had come out from Chicago on the afternoon train, and was present when Professor Barnard gave an account of his work in astronomical photography, illustrated with lantern slides. The only other paper of the evening was by Professor Pickering, who continued his illustrated description of the work of the Harvard Observatory.

The final session of the conferences was opened by Professor

Harkness on Thursday at 9:30 A.M. Dr. Laves presented a paper giving his theoretical researches on the minor planet 334. After the discussion Professor Hale described his solar investigations, and showed a number of lantern slides. The last paper was by Professor Wadsworth, on a photographic meridian circle. At its conclusion the conference adjourned. Additional papers had been presented by Professors Riccò, Safford, Very and Hull, but time did not permit them to be read.

The Trustees, members of the Faculties and guests of the University, numbering about 700, arrived from Chicago at noon, on two special trains kindly furnished for the occasion by the Chicago & North Western Railway Co. The dedicatory exercises were held in the great tower, where a platform for the speakers and chairs for the guests had been provided on the rising floor, which stood in its lowest position. The programme of the exercises was as follows:

1. The Invocation. Dean Eri B. Hulbert.
2. Music. The Spiering Quartette.
3. Address: "The Importance of Astrophysical Research and the Relation of Astrophysics to other Physical Sciences." Professor James E. Keeler, Sc.D., Director of the Allegheny Observatory.
4. Music. The Spiering Quartette.
5. Presentation. Mr. Charles T. Yerkes.
6. Acceptance on behalf of the Trustees. The President of the Board of Trustees, Mr. Martin A. Ryerson.
7. Address on behalf of the Faculties. The President of the University.
8. Prayer. Rev. James D. Butler.

Professor Keeler's address is given on another page.[1] Mr. Yerkes' remarks were as follows:

"MR. PRESIDENT, LADIES AND GENTLEMEN:

"After five years of patient waiting and incessant labor, we are brought together to perform the agreeable duty which has been in our minds during the whole of that period, namely, the dedication of this Observatory.

"It was in October of 1892 that Dr. Harper and Professor Hale arranged for the manufacture of the telescope and building the Observatory, and since that time the work has been incessant. Before this, however, three years had been spent in preparing the rough glass, making eight years in all which was required to produce what we now

[1] See page 271.

have before us. The anxiety of those who were so deeply interested in the work can scarcely be imagined, for as they followed it step by step from its incipiency to its finish, many doubts and fears naturally crossed their minds. As no glass had ever been made of the size of this there was no criterion to go by, and it was necessary to leave everything to the future. Then again, there was the risk of accident, and when the glass was safely lodged in its final resting place, the hearts of many who are now present beat much more freely and with greater satisfaction than they had since the projecting of the work. A priceless gem to these gentlemen was at last in safety, and when we consider what would have been the result in case of accident — six years of sincere work being thrown away and six years more would surely elapse before the same results could be obtained — we can imagine something of their feelings of satisfaction when they saw the final accomplishment of their labors. That we have done a good deed and one which will revert to our satisfaction we have no doubt.

"The science of astronomy, while being the oldest extant, has been, we may say, the most neglected. It is in no way commercial, and that may be one of the chief reasons. Its promulgation has always been confined to a class of enthusiasts who felt an interest in their work and gloried in the achievements which they attained.

"Five thousand years ago astronomy was studied, but it was not until six hundred years before the Christian era that any progress had been made in it. Greek mythology used it as a romance, with but little idea of its truthfulness, and up to the beginning of the seventeenth century, when the telescope was invented by Hans Lipperhay and applied by the great Galileo, but little was known of the science. From that time on through the work of Newton, Lagrange, Laplace, Dominicus Cassini, Flamsteed, Bradley, Herschel, Bessel, and others equally celebrated, good progress was made, and during the last half century there have been greater advances than ever before. This is owing to the fact that we now have the ability to determine correctly by instruments which are late inventions, matters that were never dreamed of. It is to the great telescopes that the ardent workers look for encouragement for their labors. Accurate means have been devised for recording the observations, while the photographic plate, together with the spectroscope, have been applied with the most astonishing results.

"As I said, one reason why the science of astronomy has not more

helpers, is on account of its being entirely uncommercial. There is nothing of moneyed value to be gained by the devotee to astronomy; there is nothing that he can sell. Compared with electricity and other sciences of like character, there is the greatest difference; consequently, the devotee of astronomy has as his only reward the satisfaction which comes to him in the glory of the work which he does, and the results which he accomplishes.

"These are some of the reasons why you are gathered here today and why this edifice and its contents have been erected.

"That the work will produce good results, I am, after a thorough examination, fully satisfied, and my satisfaction is still more intense when I learn of the great and enthusiastic men which the University of Chicago has gathered around it for the purpose of taking charge of the work to be performed in this Observatory. I therefore with the fullest feeling of satisfaction and pleasure, turn over to you this structure with all its contents, feeling satisfied that it is now in the best of hands, and that the labors here will be serious, conscientious, and thoroughly done. I feel that in your attempts to pierce the mysteries of the universe which are spread before you by our great Creator, the enthusiasm of your natures will carry you to success."

Mr. Ryerson expressed the thanks of the Board of Trustees to Mr. Yerkes for his gift, and dwelt upon the satisfaction they felt in the fact that the University would now be able to make further contributions to knowledge. "While recognizing fully the great practical services which astronomy has rendered to the world, I still feel that its proudest claim to recognition and appreciation must dwell in its tendency to establish and maintain in the feelings of mankind the conviction that, amid the services of science, the increase of knowledge for the sake of knowledge is not the least." In his address on behalf of the Faculties, President Harper reviewed the events in the history of the Observatory since its inception in 1892. In recounting the various gifts that have been received, he made the first public announcement of the recent gift, by that generous patron of astronomy, Miss Catherine Bruce, of $7000 for a ten-inch photographic telescope, with building and dome. He concluded by tendering to Mr. Yerkes the appreciative thanks of the Faculties of the University.[1] A very cordial letter sent for the occasion by Professor Vogel, together with congratulatory cablegrams

[1] The addresses of Mr. Ryerson and President Harper are given in full in the UNIVERSITY RECORD for October 22, 1897.

from the Vatican Observatory, Professors Tacchini, Geelmuyden, Josef and Jan Fric, Schuster and others were received.

At the conclusion of the exercises luncheon was served to the University's guests, after which an opportunity was given them to inspect the Observatory. The return to Chicago was made at 4:00 P.M.

On Friday, October 22, the visiting men of science assembled at the Ryerson Physical Laboratory of the University of Chicago, where Professors Michelson and Stratton conducted them through the building, and showed a number of interesting experiments. Among the instruments exhibited were a large interferential comparer for the production of standards of length, and a new form of harmonic analyzer. The effect of a magnetic field on radiation was beautifully shown with the aid of an interferometer.

At 1:00 P.M. the visiting men of science and other guests were entertained at luncheon by the President of the University. At 3:00 P.M. a large audience assembled in Kent Theater, where Professor Newcomb delivered his address on "Aspects of American Astronomy."[1] At the conclusion of the address Professor Hale said a few words of thanks to the men of science and official representatives of institutions for their presence at the various exercises held in connection with the dedication.

A 7:00 P.M. Mr. Yerkes gave a banquet at Kinsley's Restaurant to the visiting men of science. Toasts were responded to by Mr. Ferdinand Peck of the Board of Trustees, Professor Pickering, Professor Rees, Mr. Brashear, Professor Comstock, Professor Harkness, Professor Michelson and Professor Hale. In response to a general call, Mr. Yerkes made a few concluding remarks, in which he expressed his great satisfaction at the kindly interest in the welfare of the Observatory which had been manifested by the visiting men of science.

A list of the astronomers, astrophysicists and physicists who took part in the conferences is given below. It should be added that M. Deslandres of the Paris Observatory, and Professor Schuster of Victoria University, Manchester, visited the Observatory with the intention of taking part in the exercises, but were unable to remain, owing to the postponement of the dedication.

Professor E. E. Barnard, Yerkes Observatory, Williams Bay, Wis.

Professor N. E. Bennett, Wilmington College Observatory, Wilmington, Ohio.

[1] See page 289.

Mr. John A. Brashear, Allegheny Pa.

Mr. William R. Brooks, The Observatory, Geneva, N. Y.

Professor S. W. Burnham, Yerkes Observatory, Williams Bay, Wis.

Professor Hugh L. Callendar, McGill University, Montreal, Canada.

Mr. E. Colbert, Chicago, Ill.

Professor W. H. Collins, Haverford College Observatory, Haverford, Pa.

Professor George C. Comstock, Washburn Observatory, Madison, Wis.

Professor Henry Crew, Northwestern University, Evanston, Ill.

Professor S. usan J. Cunningham, Swarthmore College Observatory, Swarthmore, Pa.

Professor C. L. Doolittle, Flower Observatory, Philadelphia, Pa.

Mr. Ferdinand Ellerman, Yerkes Observatory, Williams Bay, Wis.

Mr. A. S. Flint, Washburn Observatory, Madison, Wis.

Professor Edwin B. Frost, Shattuck Observatory, Hanover, N. H.

Miss Caroline E. Furness, Vassar College Observatory, Poughkeepsie, N. Y.

Rev. J. G. Hagen, S. J., Georgetown College Observatory, Georgetown, D. C.

Professor George E. Hale, Yerkes Observatory, Williams Bay, Wis.

Professor Asaph Hall, Jr., Detroit Observatory, Ann Arbor, Mich.

Professor William Harkness, United States Naval Observatory, Washington, D. C.

Rev. John T. Hedrick, S. J., Georgetown College Observatory, Georgetown, D. C.

Professor G. W. Hough, Dearborn Observatory, Evanston, Ill.

Professor G. F. Hull, Colby University, Waterville, Me.

Dr. W. J. Humphreys, University of Virginia, Charlottesville, Va.

Professor Leslie H. Ingham, Kenyon College, Gambier, Ohio.

Professor James E. Keeler, Allegheny Observatory, Allegheny, Pa.

Dr. Kurt Laves, University of Chicago, Chicago.

Professor F. P. Leavenworth, University of Minnesota, Minneapolis, Minn.

Professor H. C. Lord, Emerson McMillin Observatory, Columbus, O.

Mr. Carl A. R. Lundin, Cambridge, Mass.

Professor C. H. McLeod, McGill University, Montreal, Canada.

Mr. F. R. Moulton, University of Chicago, Chicago.

Professor E. Miller, Kansas State Normal University, Lawrence, Kan.

Professor G. W. Myers, University of Illinois Observatory, Champaign, Ill.

Professor Simon Newcomb, Washington, D. C.

Professor E. F. Nichols, Colgate University, Hamilton, N. Y.

Mr. John A. Parkhurst, Private Observatory, Marengo, Ill.

Professor Henry M. Paul, U. S. Naval Observatory, Washington, D. C.

Professor W. W. Payne, Goodsell Observatory, Northfield, Minn.

Professor E. C. Pickering, Harvard College Observatory, Cambridge, Mass.

Professor Charles Lane Poor, Johns Hopkins University, Baltimore, Md.

Professor H. S. Pritchett, Superintendent U. S. Coast Survey, Washington, D. C.

Rev. A. W. Quimby, Private Observatory, Berwyn, Pa.

Professor J. K. Rees, Columbia University Observatory, New York City.

Mr. G. W. Ritchey, Yerkes Observatory, Williams Bay, Wis.

Mr. Charles H. Rockwell, The Observatory, Tarrytown, N. Y.

Professor Carl Runge, Technische Hochschule, Hannover, Germany.

Mr. Frederick H. Sears, University of California, Berkeley, Cal.

Professor B. W. Snow, University of Wisconsin, Madison, Wis.

Professor M. B. Snyder, Central High School Observatory, Philadelphia, Pa.

Professor C. D. Swezey, University of Nebraska, Lincoln, Neb.

Professor Milton Updegraff, Laws Observatory, Columbia, Mo.

Professor Winslow Upton, Ladd Observatory, Providence, R. I.

Professor J. M. Van Vleck, Wesleyan University, Middletown, Conn.

Professor Frank W. Very, Ladd Observatory, Providence, R. I.

Professor F. L. O. Wadsworth, Yerkes Observatory, Williams Bay, Wis.

Professor Mary W. Whitney, Vassar College Observatory, Poughkeepsie, N. Y.

Many other well-known men of science, who were unable to take part in the conferences, were present at the dedication exercises.

G. E. H.

ON THE VARIATIONS OBSERVED IN THE SPECTRUM OF THE ORION NEBULA.

In the current volume of the *Vierteljahrsschrift der Astronomische Gesellschaft*, pp. 51–52, Dr. J. Scheiner has paid his compliments to my spectroscopic observations, the *raison d'etre* of his blanket criticism seeming to lie in the fact that he and I differ as to the spectrum of the Orion Nebula.

In 1868 and later Sir William Huggins suspected that there were "small differences of relative brilliancy" of the three principal bright lines in the spectrum of different portions of the Orion Nebula; but he dismissed the subject with the statement that he did not have "sufficient evidence on these points."

Professor Vogel wrote in 1871: "An investigation of the different parts of the nebula gave the results that the three lines were everywhere present and that their relative intensities remained always constant."

In 1893 I found that the relative intensities of the three principal lines vary enormously in different parts of the Orion Nebula. In the region of the Trapezium the $H\beta$ line is the faintest of the three, but in many of the faint regions on the southwest border of the nebula the $H\beta$ line was found to be the brightest of the three, and in the region surrounding Bond's star No. 734 the $H\beta$ line was found to be many times as intense as the line $\lambda 5007$.

Dr. Scheiner in the above mentioned article states that he has observed the spectrum of the Orion Nebula under favorable circumstances, and has found no appreciable variations.

I have thought it best to ask some of my colleagues kindly to observe the spectrum with reference to the disputed points, and their results are published herewith.

Inasmuch as an efficient spectroscope is a most important item in the make-up of "favorable circumstances," I publish the constants for the apparatus used in the observations made here. The telescope has aperture 36 inches and focal length 694 inches. The collimator is 20½ inches long, the view telescope 10½ inches, the eyepiece magnifies 13 diameters, and the prism is a very dense 60° flint. The apparatus as a whole is very efficient for the purpose employed. Moderately high dispersion is advisable since it reduces the intensity of the continuous spectrum without reducing the intensity of the bright lines.

Will Dr. Scheiner kindly publish the constants of his apparatus in order that others may judge of his "favorable circumstances?" Again, did Dr. Scheiner see the bright lines in the region surrounding star Bond No. 734? If so, I respectfully ask that he publish his estimate of their relative intensities without delay. If he did not see them, his observations are either incomplete or his apparatus was too inefficient to bear on this problem.

Perhaps I may say that a large telescope is of some advantage in this problem, but it is not a necessity.

W. W. Campbell.

Lick Observatory,
September 8, 1897.

OBSERVATIONS OF THE SPECTRUM OF THE ORION NEBULA.

Owing to the unscientific character of Dr. Scheiner's criticism of Professor Campbell's spectroscopic work at the Lick Observatory, the latter gentleman justly considers it necessary to call in witnesses to verify his observations on the Orion Nebula, the only specific case mentioned by Dr. Scheiner.

My notes on the spectrum, as seen by me on the morning of September 8, 1897 with the 36-inch refractor, are as follows: (1) Central part of the nebula, Trapezium region. The three nebular lines, which I shall call *a*, *b*, and *c* (*a* being the one toward the red) are all conspicuous. Middle line *b* occulted by a coarse micrometer wire, and line *a* now appears three or four times as bright as *c*. Micrometer wire now moved so as to completely cover *a*, line *b* appears just a trifle brighter than *c*. (2) Region northeast of Trapezium. Nebular line *c* faint but plainly seen, but both *a* and *b* are invisible. To identify the line that was visible, the heavy micrometer wire was moved until it was just tangent to the line on the side toward the invisible lines *a* and *b*. Then by moving the whole telescope the region of the Trapezium was brought into the field of view, and the line *c* was found to coincide in position with the only nebular line that was visible in the region northeast of the Trapezium. (3) Region southwest of the Trapezium. All three nebular lines plainly visible. Line *a* occulted with the heavy micrometer wire: the line *c* is now unmistakably brighter than *b*.

Further observations on the faint outlying portions of the nebula

were stopped by the approach of dawn. The ones here described were all easily made, and showed plainly the large variations in the relative intensities of the bright lines in different regions of the nebula.

All lovers of fair play will regret that the pages of our society's publication,—the *Vierteljahrsschrift*,—should be marred by personal attacks, the foundation for the same resting, as it seems to me, simply on the unsupported opinion of the attacking party.

J. M. SCHAEBERLE.

LICK OBSERVATORY,
September 8, 1897.

VARIATIONS IN THE SPECTRUM OF THE ORION NEBULA.

THIS morning, at Mr. Campbell's request, I estimated the relative intensities of the three bright lines λ 4861, 4959, and 5007 in the visual spectrum of three different parts of the Orion Nebula.

In the region of the Trapezium the line λ5007 was estimated to be three times as bright as the line λ4861, the line λ4959 being covered by a heavy micrometer wire. Moving this wire to cover the brightest line λ5007, the other two were, as nearly as I could estimate, of the same intensity.

Bringing the spectrum of the region surrounding the star Bond No. 734 into the field of view, the line λ4861 was clearly seen, but the other two lines had disappeared entirely. The line that was visible was identified by the micrometer.

In the spectrum of a faint region southwest of the Trapezium, the line λ5007 being covered by the micrometer wire, the line λ4861 was very decidedly brighter than the line λ4959.

All the observations described were very easy to make.

R. G. AITKEN.

LICK OBSERVATORY,
September 8, 1897.

VARIATIONS IN THE SPECTRUM OF THE ORION NEBULA.

THIS morning, at the request of Professor Campbell, I examined the spectrum of the Orion Nebula.

In the vicinity of the Trapezium the three chief lines were very bright. A comparison of the relative intensities of λ5007 and *Hβ* placed the former as three or four times as bright as the latter. *Hβ* was then occulted by a coarse micrometer wire, and the slit moved to the region north following the Trapezium, in the immediate vicinity of the star Bond 734. Nothing was now visible except a faint continuous spectrum. On moving the micrometer wire, however, *Hβ* was was easily seen, apparently the only bright line on the faint background. The line was again occulted, and the slit returned to the Trapezium region. The lines λ 5007 and 4959 shone with their original brilliancy, and *Hβ* was found to be occulted. A comparison was now made between *Hβ* and λ4959. In order to eliminate effects of contrast, the chief nebular line in the Trapezium region was occulted, and λ4959 was seen to be perceptibly brighter than *Hβ*. In the south preceding region of the nebula, which was next examined, *Hβ* was found to be the brighter of the two.

Further observations were stopped by daylight. The observations described above were very easily secured, and indisputably show that the spectrum varies enormously for the different regions examined.

W. H. WRIGHT.

LICK OBSERVATORY,
September 8, 1897.

NOTE ON THE LEVEL OF SUN-SPOTS.

IN an interesting paper published in the October 1896 number of this JOURNAL, Professor Frost has summarized the objections recently urged against Wilson's doctrine on the level of Sun-spots. The evidence derived from observations of the apparent width of the penumbra at various distances from the Sun's limb is so contradictory that too great reliance should not be placed upon it. On the depression side we have the observations of Wilson, supported by those of De la Rue, Stewart and Loewy, Secchi and others. Professor Riccò's recent paper[1] affords further evidence, apparently of the strongest character, in favor of this long-established view. As opposed to these results we have the contrary conclusions of Howlitt and Sidgreaves, whose observations lead them to believe that spots are convex rather than concave.

[1] "On the Level of Sun-spots and the Cause of their Darkness," this JOURNAL, **6**, 91, August, 1897.

In endeavoring to ascribe proper weight to such contradictory results it should be noted that opposite conclusions have been drawn from observations of the same spots by different astronomers. On the whole, however, I am inclined to regard the advocates of the Wilsonian doctrine as having rather the better of the argument, particularly as the results of De la Rue, Stewart and Loewy were derived from a study of photographs.

Those who have enjoyed frequent opportunities to observe Sun-spots with suitable instruments, under atmospheric conditions sufficiently good to render visible the exquisite details recorded by Langley, will probably be inclined to favor the view of Wilson. In any case they will hardly be ready to admit that the umbra is at a higher level than the penumbra, for it cannot be doubted that the penumbral filaments overlie the umbra, and frequently unite to form bridges extending completely across it.

It must nevertheless be admitted that direct observations of spots at the limb frequently seem to tell against the Wilsonian view. As Father Sidgreaves has pointed out[1] the notches there seen and photographed are difficult to account for on the ordinary depression theory. It will presently be shown, however, that it is perhaps hardly necessary to proceed at once to the conclusion that spots are of "a mountainous rather than a cavernous form."

But the difficulty just referred to is not the most serious one that confronts the Wilsonian doctrine. Both Langley and Frost have found that the ratio of umbral radiation to that of the neighboring photosphere undoubtedly increases with the distance from the center of the Sun. We thus seem forced to conclude that the umbral region whose radiation was measured was above the level of the photosphere, and consequently subjected to less absorption.

At first sight this conclusion seems to be at variance with the idea that spots are depressions, and it has been so treated by various writers. But may we not consider spots to be hollows in comparatively small areas of the photosphere which are raised above the ordinary level? The suggestion is one which would naturally present itself, but as I have seen no mention of this view, it seems worth while to call attention to it. On this idea the cross section of a spot would have some such form as is roughly indicated in Fig. 1.

a, *a*, *a*, is the ordinary level of the photosphere; *p*, *p*, the penumbra,

[1] *Monthly Notices*, **55**, 285, 1895.

and *u* the umbra of a spot. In order to account for the results obtained by Langley and Frost it is necessary to assume that *u* is above the level *a*, *a*, *a*. We must, however, at the same time assume that the radiation of the photosphere was measured at some point outside the elevated region. In answer to an inquiry regarding this point, Professor Frost informs me that in such measures his thermopile was placed at a distance from the center of the spot amounting to some three or four diameters of the umbra. For this reason he is inclined to regard the suggestion as a plausible one. To me it seems to

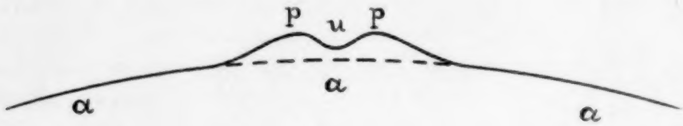


FIG. 1.

reconcile the conflicting testimony offered by the supporters of the two views. Apparent notches at the Sun's limb may be accounted for by assuming that the side of the spot nearest us is somewhat lower than the opposite penumbra. The darkening of the limb due to the smaller radiation of the penumbra might thus produce both the visual and the photographic effects. An actual notch would result from opposite depressions (lying in the line of sight) of the encircling photospheric ring. In such a case one would be likely to see a depression rather than two elevations on account of the increased effect of contrast, and also because the slope of the inner walls would probably be much sharper than that of the outer ones.

It is evident that this simple suggestion, which may very likely break down before a more searching criticism than I have yet had an opportunity to give it, can be subjected to a very definite test.[1] If measures of photospheric radiation be made close to the edge of the penumbra, we should find that the ratio umbra: photosphere *decreases* as the limb is approached. This is on the assumption that the umbra is appreciably below the bordering photosphere. It may, however, be nearly on a level with it, in which case the ratio should of course remain nearly constant at all distances from the limb.

GEORGE E. HALE.

YERKES OBSERVATORY,
October 1897.

[1] Unless the slope of the encircling ring of photosphere is very abrupt.

NOTE ON THE PRESENCE OF VANADIUM IN RUTILE.

In the August-number of the ASTROPHYSICAL JOURNAL I find a note on the Presence of Vanadium in Rutile, in which it is stated that Professor Rowland made this discovery some four or five years ago. I was not aware of this fact when I published my paper on the chemical constitution of rutile, otherwise I would naturally have duly mentioned it. At all events my observation was thus wholly independent, The more so, as up to the present date any publication of Professor Rowland's discovery hat not come to my knowledge. As I am in possession of by far the greatest part of spectroscopic literature such a publication could only with difficulty have escaped me.

B. HASSELBERG.

NOTICE.

The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention will be given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

In the department of *Minor Contributions and Notes* subjects may be discussed which belong to other closely related fields of investigation.

It is intended to publish in each number a bibliography of astrophysics, in which will be found the titles of recently published astrophysical and spectroscopic papers. In order that this list may be as complete as possible, and that current work in astrophysics may receive appropriate notice in other departments of the JOURNAL, authors are requested to send copies of all papers on these and closely allied subjects to both Editors.

Articles written in any language will be accepted for publication, but unless a wish to the contrary is expressed by the author, they will be translated into English. Tables of wave-lengths will be printed with the short wave-lengths at the top, and maps of spectra with red end on the right, unless the author requests that the reverse procedure be followed. If a request is sent *with the manuscript* one hundred reprint copies of each paper, bound in covers, will be furnished free of charge to the author. Additional copies may be obtained at cost price. No reprints can be sent unless a request for them is received before the JOURNAL goes to press.

The Editors do not hold themselves responsible for opinions expressed by contributors.

The ASTROPHYSICAL JOURNAL is published monthly except in July and September. The annual subscription price for the United States, Canada and Mexico is $4.00; for other countries in the Postal Union it is 18 shillings. Correspondence relating to subscriptions and advertisements should be addressed to *The University of Chicago, University Press Division, Chicago, Ill.*

Wm. Wesley & Sons, 28 Essex St., Strand, London, are sole foreign agents and to them all European subscriptions should be addressed.

All papers for publication and correspondence relating to contributions and exchanges should be addressed to *George E. Hale, Yerkes Observatory, Williams Bay, Wisconsin, U. S. A.*

THE PHYSICAL REVIEW

A JOURNAL OF EXPERIMENTAL AND THEORETICAL PHYSICS

CONDUCTED BY

EDWARD L. NICHOLS

ERNEST MERRITT, AND FREDERICK BEDELL

BEGINNING with Volume V. (July–December, 1897), two volumes of THE PHYSICAL REVIEW will be published annually, these volumes beginning in July and January, respectively, and containing at least five numbers each. The price of subscription is two dollars and fifty cents a volume (five dollars a year), or fifty cents a number. Subscription should be sent to the publishers, THE MACMILLAN COMPANY, *66 Fifth Avenue, New York;* Messrs. MACMILLAN & CO., LTD., *London;* or to Messrs. MAYER & MUELLER, *Berlin.*

Volumes I–IV of THE PHYSICAL REVIEW are annual volumes, each containing six bi-monthly numbers, beginning with the July–August number, 1893. These may be obtained from the publishers at the former subscription price three dollars per volume.

Correspondence relating to contributions should be addressed to the editors, at *Ithaca, New York.*

Manuscript intended for publication in THE PHYSICAL REVIEW must be communicated by the author; when publication in other journals is contemplated, notice to this effect should be given.

The author of original articles published in the REVIEW will receive one hundred separate copies in covers, for which no charge will be made; additional copies, when ordered in advance, may be obtained at cost.

PUBLISHED FOR CORNELL UNIVERSITY.

THE MACMILLAN COMPANY, NEW YORK.

The Larkin Soaps

The Whole Family supplied with Laundry and Toilet Soaps for a year at Half Price. Sent Subject to Approval and Payment after Thirty Days' Trial.

IT IS WISE ECONOMY TO USE GOOD SOAP. Our soaps are sold entirely on their merits, with our guarantee of purity. THOUSANDS OF FAMILIES USE THEM, and have for many years, in every locality, many in your vicinity.

The Larkin Plan

saves you half the regular retail prices; half the cost. You pay but the usual retail value of the soaps and all middlemen's profits are yours in a premium, itself of equal value. One premium is **A White Enameled, Steel, Brass-Trimmed Bed.** Metallic beds add beauty and cheerfulness to the chamber, while they convey a delightful feeling of cleanliness that invites repose. They harmonize perfectly with furniture of any wood or style. Brass top rod at head and foot, and heavy brass, gold-lacquered trimmings. Very strong and will last a lifetime. Malleable castings, will never break. Detachable lignum-vitæ ball-bearing casters. 4 feet 6 in. wide. 6 feet 6 in. long. Head, 4 feet 5½ in. Foot, 3 feet 2½ in. high. Corner posts are 1 inch in diameter. The bed is the Article of Furniture Supreme: In it a Third of Life is Passed.

If, after thirty days' trial, the purchaser finds all the Soaps, etc., of excellent quality and the premium entirely satisfactory and as represented, remit $10.00; if not, notify us goods are subject to our order. We make no charge for what you have used.

*If you remit in advance, you will receive in addition a nice present for the lady of the house, and shipment day after order is received. Money refunded promptly if the **Box** or **Premium** does not prove all expected. Safe delivery guaranteed.*

☞ Many youths and maidens easily earn a Chautauqua Desk or other premium free by dividing the contents of a Combination Box among a few neighbors who readily pay the listed retail prices. This provides the $10.00 needful to pay our bill, and gives the young folk the premium as "a middleman's profit." The wide success of this plan confirms all our claims.

Booklet Handsomely Illustrating 15 Premiums sent on request.

THE LARKIN SOAP MFG. CO., Buffalo, N. Y.

Estab. 1875. Incor. 1892. Capital, $500,000.

Our Great Combination Box.

Enough to last an Average Family one Full Year.

This List of Contents Changed as Desired.

100 BARS "SWEET HOME" SOAP For all laundry and household purposes it has no superior.	**$5.00**
10 BARS WHITE WOOLLEN SOAP A perfect soap for flannels.	**.70**
12 Pkgs. BORAXINE SOAP POWDER (full lbs.) An unequalled laundry luxury.	**1.20**
4 BARS HONOR BRIGHT SCOURING SOAP	**.20**
1-4 DOZ. MODJESKA COMPLEXION SOAP Perfume exquisite. A matchless beautifier.	**.60**
1-4 DOZ. OLD ENGLISH CASTILE SOAP	**.30**
1-4 DOZ. CREME OATMEAL TOILET SOAP	**.25**
1-4 DOZ. ELITE GLYCERINE TOILET SOAP	**.25**
1-4 DOZ. LARKIN'S TAR SOAP Unequalled for washing the hair.	**.30**
1-4 DOZ. SULPHUR SOAP	**.30**
1 BOTTLE, 1 oz., MODJESKA PERFUME Delicate, refined, popular, lasting.	**.30**
1 JAR, 2 ozs., MODJESKA COLD CREAM Soothing. Cures chapped hands.	**.25**
1 BOTTLE MODJESKA TOOTH POWDER Preserves the teeth, hardens the gums, sweetens the breath.	**.25**
1 STICK WITCH HAZEL SHAVING SOAP	**.10**
THE CONTENTS, Bought at Retail, Cost	**$10.00**
THE PREMIUM, worth at Retail	**10.00**
All for $10. (You get the Premium you select, gratis.)	**$20**

NOTE.—The management of this paper have inspected the soaps and premiums, and know they give satisfaction, and also know that the Larkin Soap Mfg. Co. is reliable in every way, and fulfill all their promises as advertised above.—*Baptist Union, Chicago.*

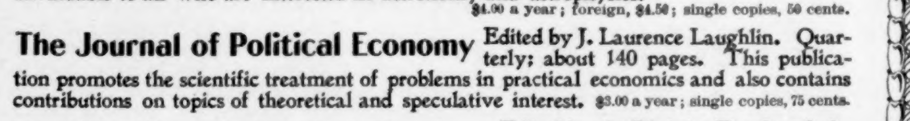
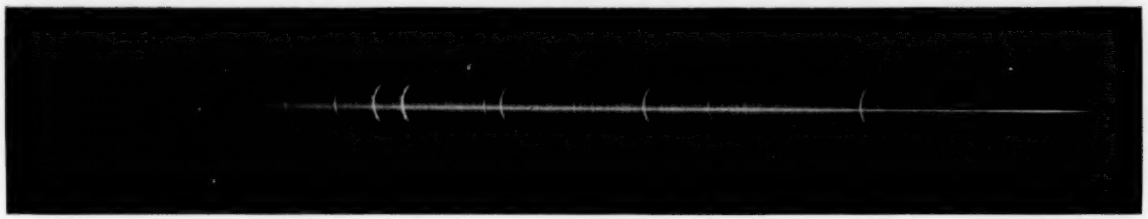


PLATE XXI.



PHOTOGRAPH OF THE "FLASH SPECTRUM," MADE WITH A PRISMATIC CAMERA BY MR. W. SHACKLETON AT THE TOTAL SOLAR ECLIPSE OF AUGUST 8, 1896.